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COLORADO DISCHARGE PERMIT SYSTEM (CDPS)

SUMMARY OF RATIONALE

METRO WASTEWATER RECLAMATION DISTRICT

CDPS PERMIT NUMBER CO-0026638, ADAMS COUNTY

TABLE OF CONTENTS

I. TYPE OF PERMIT — *Fourth Renewal*

II. FACILITY INFORMATION

A. Facility Type: *Domestic- Major Municipal, Mechanical Plant*

B. Facility Classification: *Class A per Section 100.9.2 of the Regulations for Certification of Water Treatment Plant and Wastewater Treatment Plant Operators.*

C. Fee Category: *Category 21, Subcategory 10*
Category Flow Range: *Sewage from 100,000,000 gallons per day or over*
Annual Fee: *17,926*

D. Legal Contact:
Robert W. Hite, District Manager
Metro Wastewater Reclamation District
6450 York Street
Denver, CO 80229-7499
303-286-3000

E. Facility Contact:
Steve Walker
Metro Wastewater Reclamation District
6450 York Street
Denver, CO 80229-7499
303-286-3000

F. Facility Location: *NW ¼, Section 12, T3S, R68W, 6th P.M.*

G. Discharge Point:
001A, following disinfection, from the North Complex to the South Platte River
002A, following disinfection, from the South Complex to the South Platte River
001C, reporting point for the physical discharge points 001A, and 002A
003A, following disinfection, to the Burlington Canal
004A-F, facility drain/stormwater system, these discharge points are being removed from the permit. Water from the drain system is now routed to the headworks of the treatment facility
005A, Discharge to the South Platte River through the percolation pit, this discharge is no longer being used and will be removed from the permit

III. RECEIVING STREAM

Evaluation of the receiving stream and its assimilative capacities are included as Appendicies A through E to this rationale. These Appendices were prepared by Dr. William Lewis and Dr. James Saunders in cooperation with South Platte CURE, and are listed here:

Appendix A – Basis for Permitting
Appendix B – Supplement to the South Platte River Segment 15 Water Quality Assessment Reallocation of Assimilative Capacity for Selected Constituents
Appendix C – Segment 15 Water Quality Model Recalibration for 2002 and Use of the Model in Support of Permitting for Ammonia, CBOD, and Dissolved Oxygen
Appendix D – Segment 15 Water Quality Model Recalibration for 2002 and Use of the Model in Support of Permitting Identification, Classification and Standards Addendum for Nitrate
Appendix E – South Platte River Segment 15 Water Quality Assessment Analysis and Modeling in Support of Permitting on Lower Sand Creek and the Upper Portion of Segment 15, South Platte River
Appendix F - Total Maximum Daily Load Assessment, Dissolved Oxygen, South Platte River – Segment 15,Burlington Ditch To Big Dry Creek, Adams And Weld Counties, Colorado, Public Notice Draft – February 25, 2000

IV. FACILITIES EVALUATION

A. Infiltration/Inflow (I/I)

No infiltration/inflow problems have been documented in the service area.

B. Lift Stations

The Metro District owns and operates four (4) lift stations.

Table IV-1 summarizes the information available on Metro Wastewater Reclamation District's lift stations.

Table IV-1 - Lift Station Summary

Lift Station	Storage (gallons)	Pump No.	Pump Capacity (gpm)	Pump Capacity (HP)	Average Daily Flow (MGD)	Peak Flow (MGD)	Firm Pump Capacity (MGD)	Forcemain Capacity (MGD)	% Pump Capacity (Peak/Firm)
Thornton	1,641,000	1	9000	250					
North		2	9000	250					
Washington		3	9000	250					
Lift Station		4	6940	150					
		Total:	33940		11.5	30.9	35.4	43.6	86
Brantner	151,000	1	2100	300					
Gulch		2	4200	300					
Lift Station		3	4200	300					
		4	2100	200					
		Total:	12600		3.0	9.37	12.1	10.9	77
Governors	42,047	1	840	40					
Ranch		2	840	40					
Lift Station		3	840	40					
		4	840	40					
		Total:	3360		0.39	1.56	3.6	4.8	43
Denargo	33,750	1	200	N/A					
Market		2	200	N/A					
Lift Station		Total:	400		N/A	N/A	0.3		N/A

C. Facility Modifications and Resulting Changes in Capacity

The facility consists of north and south treatment trains. Each of the treatment trains has its own barscreens, and grit removal. The North Facility includes 10 primary clarifiers, 12 aeration basins, 12 secondary clarifiers, chlorination, and dechlorination. The South Facility includes 4 primary clarifiers, 8 aeration basins, 10 secondary clarifiers, chlorination, and dechlorination. Sludge from the primary clarifiers is blended and treated in 10 anaerobic digesters, gas from this anaerobic digestion feeds a co-generation facility that provides for plant power needs. The permittee has not performed any construction at this facility that would change the monthly hydraulic capacities of 177.8 MGD to 227.0 MGD or the organic capacity of 169.5 tons BOD_5/day which were specified in the rationale for the previous permit and that document should be referred to for this information. These capacities will continue in this permit. The effluent flow is measured by continuous flow recorders and totalizers.

D. Sludge Treatment and Disposal

Metro maintains the goal to land apply all of the Class B biosolids produced. During inclement weather Class B biosolids is diverted from land application for processing as a Class B biosolids product to be land applied, or a Class A Compost biosolids product for unrestricted use. In the event Class A or B pollutant criteria cannot be met, the biosolids will be landfilled.

V. PERFORMANCE HISTORY

A. Monitoring Data

1. Table V-1 summarizes the effluent data reported on the monthly Discharge Monitoring Reports (DMR's) for the Metro Wastewater Reclamation District facility, Outfall 001C, from June 1999 through May 2001.

Table V-1 - Self-Monitoring Results

Parameter	# Samples or Reporting Periods	Reported Concentrations Average/Minimum/Maximum			Previous Permit Limit	No. of Limit Excursions
Influent Flow, MGD	24	157.0	141	182	177.8 – 227*	NA
Effluent Flow, MGD	24	147.0	104	174	177.8 – 227	0
Influent BOD_5, mg/l	24	206.1	165	244	NA	NA
Influent BOD_5, lbs/day	24	267,738	247,881	315,426	339,000*	NA
Effluent $CBOD_5$, mg/l	24	7.04	5	10	17	0
BOD_5 Removal, %	24	96.58	96	98	85	0
Influent TSS, mg/l	24	233.0	202	251	NA	NA
Effluent TSS, mg/l	24	14.83	12.0	22.0	30	0
TSS Removal, %	24	93.58	91	95	85	0
Fecal Coliform, #/100 ml	24	70.58	17	230	2,000	0
Total Residual Chlorine, mg/l	24	0	0	0	0.011	0
Oil & Grease, mg/l	24	0	0	0	10	0
pH, s.u.	48	6.56	6.3	7.4	6.0 – 9.0	0
Ammonia, Total, mg/l as N	24	8.04	5.1	13.1	10 – 15	0
Total Nitrite as N, mg/l	24	0.27	0.08	0.68	1	0
Total Nitrite plus Nitrate as N, mg/l	24	4.31	3.4	6.0	10	0
Effluent Temperature, Centigrade	48	18.9	14.0	25.0	NA	NA

Continued On Next Page

Table V-1 - Self-Monitoring Results - Continued

Parameter	# Samples or Reporting Periods	Reported Concentrations Average/Minimum/Maximum			Previous Permit Limit	No. of Limit Excursions
Effluent DO, mg/l	24	5.46	4.9	5.9	4.5 – 5.0	0
Cyanide, WAD, ug/l	24	0	0	0	30	0
Total Arsenic, ug/l	24	0	0	0	50	0
Manganese, Dissolved, ug/l	24	45.0	34.0	57.0	400	0
Total Selenium as Se, ug/l	24	1.77	0	7.4	8	0
Chromium, Hex as Cr, ug/l	24	0	0	0	11	0
Zinc, PD, ug/l	24	40.8	33	53	219	0
Silver, PD, ug/l	24	0.09	0	0.29	1.4	0
Copper, PD, ug/l	24	7.3	4.4	13.3	24.6	0
Cadmium, PD, ug/l	24	0	0	0	2.23	0
Lead, PD, ug/l	24	0	0	0	13.1	0
Mercury, PD, ug/l	24	0	0	0	0.4	0
Nickel, PD, ug/l	24	1.25	0	30	184	0
Influent Diazinon, mg/l	16	0.01	0	0.15	NA	NA
Effluent Diazinon, mg/l	16	0.02	0	0.12	NA	NA
Tetrachloroethene, ug/l	24	0.07	0	1.71	5	0
WET, chronic						
Ceriodaphnia	24	-	Fail	Pass	Pass/Fail	2
Fathead Minnows	24	-	Pass	Pass	Pass/Fail	0

** - This is a facility capacity and not a permit limit.*
L = greater than or equal to
k = less than

2. *State sampling results for the Metro Wastewater Reclamation District treatment plant are summarized in Table V-2 for the previous 24 month period.*

Table V-2 - Summary of State Sampling Results

Date	Flow MGD	Temp °F	pH su	DO mg/l	TRC mg/l	Oil&Grease mg/l	Fec.Col. #/100 ml	BOD mg/l	TSS mg/l	NH_3-N mg/l
5/8/01	155.0			7.69	<0.05	<10.0	110	4	14	3.8

< - *"less than"*
* *these values exceed permit limits*

B. *Compliance With Terms and Conditions of Previous Permit*

The data shown in the preceding tables indicates that the Metro Wastewater Reclamation District facility has maintained compliance with the previous permit with the exceptions of violations of the WET limitations relative to ceriodaphnia.

VI. TERMS AND CONDITIONS OF PERMIT

A. Determination of Effluent Limitations

1. Effluent Limitations - The following limits will apply and are discussed in Sections VI-A.2 and VI-A.3.

Table VI-1 - Effluent Limits (Outfall 001C if not stated as another outfall)

Parameter	Limit	Rationale
Flow, MGD, Outfall 001C		
January	183.3 [a]	Design Capacity
February	182.2 [a]	Design Capacity
March	195.0 [a]	Design Capacity
April	207.0 [a]	Design Capacity
May	227.0 [a]	Design Capacity
June	224.8 [a]	Design Capacity
July	208.0 [a]	Design Capacity
August	211.9 [a]	Design Capacity
September	204.9 [a]	Design Capacity
October	203.5 [a]	Design Capacity
November	190.6 [a]	Design Capacity
December	177.8 [a]	Design Capacity
Flow, MGD, Outfall 003A	Report	Design Capacity
$CBOD_5$, mg/l		
Outfall 001C	17/25 [b]	TMDL/Water Quality Standards
Outfall 003A	25/40 [b]	State Effluent Regulations
TSS, mg/l, Outfalls 001C & 003A	30/45 [b]	State Effluent Regulations
E. Coli., no/100 ml, Outfall 003A	630/1,260 [e]	State Effluent Regulations
E. Coli., no/100 ml, Outfall 001C		
through December 31, 2003	630/1,260 [e]	Water Quality Standards
beginning January 1, 2004	126/252 [e]	Water Quality Standards
Total Residual Chlorine, mg/l		
Outfall 001C	0.011/0.019 [f]	Water Quality Standards
Outfall 003A	Report [c]	State Effluent Regulations
pH, s.u., Outfalls 001C & 003A	6.0-9.0 [d]	Water Quality Standards
Oil and Grease, mg/l,		
Outfalls 001C & 003A	10 [c]	State Effluent Regulations
Cyanide, Weak Acid Dissociable, ug/l	Report [a]	Water Quality Standards
Total Ammonia (as N), mg/l		
January through February	15.0/Report [f]	TMDL/Water Quality Standards
March through April	14.0/Report [f]	TMDL/Water Quality Standards
May through June	13.0/Report [f]	TMDL/Water Quality Standards
July	10.0/21.5 [f]	TMDL/Water Quality Standards
August	9.7/23.4 [f]	Water Quality Standards
September	10.0/Report [f]	TMDL/Water Quality Standards
October	10.0/23.4 [f]	TMDL/Water Quality Standards
November	14.0/24.1 [f]	TMDL/Water Quality Standards
December	15.0/Report [f]	TMDL/Water Quality Standards
Nitrate plus Nitrite, mg/l as N through May 31, 2004	10 [a]	Interim Limit

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Table VI-1 - Effluent Limits - Continued

Parameter	Limit	Rationale
Nitrate Plus Nitrite, mg/l as N, effective June 1, 2004		
January	*11.4* [c]	*Water Quality Standards*
February	*10.9* [c]	*Water Quality Standards*
March	*11.1* [c]	*Water Quality Standards*
April	*11.2* [c]	*Water Quality Standards*
May	*11.1* [c]	*Water Quality Standards*
June	*14.5* [c]	*Water Quality Standards*
July	*11.6* [c]	*Water Quality Standards*
August	*11.7* [c]	*Water Quality Standards*
September	*10.9* [c]	*Water Quality Standards*
October	*11.1* [c]	*Water Quality Standards*
November	*10.9* [c]	*Water Quality Standards*
December	*11.1* [c]	*Water Quality Standards*
Dissolved Oxygen (minimum), mg/l	*5.0/3.0* [g]	*TMDL/Water Quality Standards*
Arsenic, Total, ug/l	*Report* [c]	*Water Quality Standards*
Cadmium, PD, ug/l	*Report* [f]	*Water Quality Standards*
Chromium, Hex, Dissolved, ug/l	*Report* [f]	*Water Quality Standards*
Copper, PD, ug/l		
through March 31, 2005	*24.6* [a]	*Interim Limit*
beginning April 1, 2005	*16.9/26.4* [f]	*Water Quality Standards*
Iron, PD, ug/l	*Report* [a]	*Water Quality Standards*
Lead, PD, ug/l	*Report* [a]	*Water Quality Standards*
Manganese, PD, ug/l	*Report* [a]	*Water Quality Standards*
Mercury, PD, ug/l	*0.4/2.4* [f]	*Water Quality Standards*
Nickel, PD, ug/l	*Report* [c]	*Water Quality Standards*
Selenium, PD, ug/l	*4.6/18.4* [f]	*Water Quality Standards*
Silver, PD, ug/l	*1.1/7.0* [f]	*Water Quality Standards*
Zinc, PD, ug/l	*Report* [f]	*Water Quality Standards*
Tetrachloroethene, ug/l	*Report* [a]	*Water Quality Standards*
Diazinon, ug/l	*Report* [f]	*Toxicity Identification*
WET, Chronic Lethality	*Statistical Difference and IC25 < IWC = 98.6%* [c]	*State Permit Regulations*

[a] *30-day average*
[b] *30-day average/7-day average*
[c] *Daily Maximum*
[d] *Minimum-Maximum*
[e] *30-day geometric mean/7-day geometric mean*
[f] *30-day average/daily maximum*
[g] *7-day average minimum/Instantaneous minimum*

2. *Discussion of Effluent Limitations*

   a. *<u>$CBOD_5$, TSS, and Oil and Grease</u> - $CBOD_5$, TSS, and Oil and Grease limits are taken from State Effluent Regulations.*

   b. *<u>Dissolved Oxygen</u> – The dissolved oxygen limits as listed in the TMDL, Appendix F, have been applied as permit limits. The TMDL stated that Metro Wastewater Reclamation District will be responsible for constructing all reaeration structures and other physical improvements in the channel that are necessary to meet the dissolved oxygen standards.*

Metro District has completed three dissolved oxygen drop structures on the South Platte River since the stream channel improvements program was initiated during 1992.

Reaeration Structure No.1 is a horseshoe shaped facility with the boat chute located in the center of the structure. It is located approximately 4,000 feet upstream of the 88th Avenue Bridge. It became operational during December 1995. The project cost for this facility was $4.0 million. Once constructed, this first structure was field tested to confirm its performance in improving dissolved oxygen before the District proceeded with additional structures.

Reaeration Structure No. 2 is a curvilinear shaped structure with the boat chute located on the outside bend of the structure. This facility is located approximately 3,500 feet downstream of the 104th Avenue Bridge. This facility became operational during November 2000. The project cost for this facility was $4.4 million.

Reaeration Structure No. 3 is also a curvilinear shaped structure, which is located east of the Adams County Fairgrounds at 130th Avenue extended. This facility became operational during December 2001. The project cost for this facility was $3.5 million. This brings the total project cost for the three structures to $11.9 million.

In addition, the Metro District cooperated with Urban Drainage and Flood Control District on the construction of a grade control structure to stabilize the South Platte River in the vicinity of 124th Avenue. Urban Drainage added some reaeration improvements to its standard grade control design, and it is expected that these enhancements will be used on future grade control structures Urban Drainage builds in the river. While these modified grade control structures will not be as efficient for adding dissolved oxygen as the specifically designed drop structures, they will contribute to the improvement of dissolved oxygen in the River.

A compliance schedule will be included in the permit requiring the permittee to report on the need for addition reaeration structures, and if additional structures are needed, to construct those structures.

c. *pH - This parameter is limited by Water Quality Standards.*

d. *Pollutants Limited by Water Quality Standards – William M. Lewis, Jr. and James F. Saunders, III have made a preliminary determination of the assimilative capacity for parameters of concern for this facility and other dischargers to segment 15 of the South Platte River and Sand Creek which is tributary to the South Platte. This assessment can be found in Appendices A through E of the rationale. The Permits Unit evaluated the assimilative capacity for each parameter and determined whether there is a reasonable potential for the facility discharge to cause or contribute to an exceedance of a stream standard. If there is a reasonable potential for the discharge to contribute to an exceedance, limits are included in the permit.*

As listed in Appendix E of this rationale, assimilative capacities equal to the stream standards for coliform, chlorine, and metals were evaluated to determine if there is reasonable potential for this discharge to cause or contribute to an exceedance of the stream standards for each of these parameters. Limits for those parameters that have a reasonable potential will be included in the Metro permit. Because Metro is the predominant discharger in this segment and because the Metro discharge was modeled at flows lower than the permitted flow limit, Metro's discharge of concentrations of coliform and metals at or below the stream standards will make additional assimilative capacity available.

Coliform - Metro has requested that the E. Coli standard be utilized in establishing their coliform permit limit. The 30-day geometric mean limit will be set at the stream standard of 126 organisms per 100 ml, and the 7-day geometric mean limit will be set equal to twice the 30-day limit. Because Metro has concerns the current disinfection facilities may not be adequate to treat the permitted flows, a compliance schedule will be included in the permit requiring Metro to complete an evaluation of the need for an upgrade of the disinfection facilities at the plant on or before July 1, 2003. If the disinfection facilities are not capable of meeting the final E. coli limits, Metro will need to request an amendment to the permit at the time that the disinfection facilities evaluation is submitted to the Division.

Prior to January 1, 2004, an E. coli. limit equal to the E. coli. standard associated with the previous fecal limit will be included in the permit. If the permittee determines that the existing facility is not sufficient to treat to the final permit limits, the permittee should request an amendment to the permit to upgrade the disinfection system at the time that the disinfection system study is submitted.

Chlorine - The total residual chlorine limits will be set equal to the stream standards of 0.011 mg/l, chronic and 0.019 mg/l acute.

Cyanide - For cyanide, the standard for the receiving stream is based upon "free" cyanide concentrations. However, there is no analytical procedure for measuring the concentration of free cyanide in a complex effluent. Therefore, ASTM (American Society for Testing and Materials) analytical procedure D2036-81, Method C, will be used to measure weak acid dissociable (WAD) cyanide in the effluent. This analytical procedure will detect free cyanide plus those forms of complex cyanide that are most readily converted to free cyanide.

The cyanide effluent limitation is considered to be equal to the stream standard of 0.005 mg/l and less than the detection limit of 0.030 mg/l for WAD cyanide. Because self-monitoring data indicates that the Metro discharge does not represent a reasonable potential to cause or contribute to an exceedance of the stream standard, WAD cyanide monitoring only will be specified in the permit.

Radioactive Materials - Metro submitted four 2001 radioactive materials screenings of the Metro combined final effluent. It is anticipated that since the Lowry landfill wastewater treatment facility has been brought into full operation, this data will be representative of effluent typically discharged by Metro since the Lowry landfill wastewater treatment facility has been operational. Review of these test results and pretreatment sampling for the Lowry facility indicated that effluent concentrations of regulated radioactive parameters are far below the allowable concentrations for surface waters.

Metals - Calculated metals limits for the Metro facility, as listed in Appendix E to this rational, and metals self monitoring data were evaluated to establish what effluent metals presented a reasonable potential to cause or contribute to an exceedance of the streams standards. Due to effluent concentrations greater than half of the proposed effluent limits, data indicated the effluent concentrations of selenium, silver, and copper did present a reasonable potential to cause or contribute to exceedances of the stream standards for these parameters. Because the detection limit used for mercury monitoring was half of the chronic mercury limit and all of the data indicated concentrations below the detection limit, it could be determined that the facility had been meeting the permit limit, however reasonable potential to cause or contribute to an exceedance could not be determined. Permits limits and weekly monitoring will be included for selenium, silver, copper, and mercury.

Because data indicates that the Metro facility may not be able to dependably meet the copper limits, the copper limit from the previous permit will be included in the permit and effective through March 31, 2005. A compliance schedule will be included in the permit requiring Metro to evaluate the feasibility of reducing wastewater copper concentrations. The copper limits established in Appendix E of this rationale will become effective April 1, 2005.

Metro has stated that they plan to take actions to try and change the stream copper standard. Should the stream standards be changed, the permit will be opened and the new standards will be incorporated into the permit as copper limits.

Because the Metro discharge does not present a reasonable potential to cause or contribute to an instream exceedance of the stream standards for arsenic, manganese, nickel, chromium, zinc, cadmium, and lead, no limits will be included in the permit for these parameters. Routine monitoring will be included in the permit to maintain data for reasonable potential evaluation in the next permit for arsenic, manganese, nickel, chromium, zinc, iron, cadmium, and lead.

For metals with dissolved standards, corresponding effluent limits are based upon the potentially dissolved method of analysis, except for hexavalent chromium, which must be analyzed by using the dissolved method. For standards based upon the total and total recoverable methods of analysis, the limits are based upon the same method as the standard, except for arsenic. For arsenic, the total recoverable analyses must be performed using a graphite furnace. This method may produce erroneous results and may not be available to the permittee. Therefore, the total method of analysis will be specified instead of the total recoverable method.

<u>Ammonia</u> - The resulting calculated limits for chronic and acute total ammonia listed in Appendix C to this rationale will be set as permit limits. Because ammonia concentrations in domestic wastewater are not anticipated to exceed 25 mg/l, and because self-monitoring data indicates that maximum effluent total ammonia concentrations have not exceeded 15 mg/l, for those months where an ammonia limit is equal to or greater than 25 mg/l, reporting will be included in the permit, but no permit limit will be included. Three times per week monitoring of effluent ammonia concentration will be required in the permit.

<u>Nitrate</u> - To assure compliance with the drinking water nitrate standards that are in effect at the Thornton Well Fields the nitrate limits established in Appendix D will be included in the permit as limitations of nitrate plus nitrite. Because facility design review indicates that this facility may not be capable of consistently meeting these limits, a compliance schedule will be included in the permit requiring a study of the facility's nitrogen treatment capability.

<u>Outfall 003A</u> – Limits for Outfall 003A were established in correspondence to the State <u>Regulations For Effluent Limitations</u>. Compliance with the fecal coliform limit will be considered to be met by compliance with an e. coli limit equal to the e. coli. standard associated with the 2,000 organisms/100ml fecal coliform standard, 630 organisms/100ml e. coli..

e. *<u>Antidegradation</u> - Since the receiving water is Use Protected, an antidegradation review is not required pursuant to section 31.8(2)(b) of <u>The Basic Standards and Methodologies for Surface Water</u>.*

f. *<u>Economic Reasonableness Evaluation</u> - The Water Quality Control Commission, during their proceedings to adopt the Classification and Numeric Standards for the South Platte River Basin, considered the economic reasonableness of imposing the classification and standards listed in section VI.A. of this rationale. Since this is not a new discharger and no new information has been presented regarding the classifications and standards, the water quality standard-based effluent limitations of this permit are determined to be reasonably related to the economic, environmental, public health and energy impacts to the public and affected persons in accordance with Section 61.11 of the Colorado Discharge Permit System Regulations. If the permittee disagrees with this finding, pursuant to 61.11(b)(ii), the permittee should submit all pertinent information to the Division during the public notice period.*

B. Monitoring

1. Influent and Effluent Monitoring - Influent and effluent monitoring will be required as shown in Tables VI-2 and VI-3. Refer to the permit for locations of monitoring points.

Table VI-2 - Influent Monitoring Requirements –Monitoring Point 300I

Parameter	Measurement Frequency	Sample Type
Influent Flow, MGD	Continuous	Recorder **
Influent BOD_5, mg/l (lb/day)	Daily	24-Hour Composite
Influent Total Suspended Solids, mg/l	Daily	24-Hour Composite

* If more than one source is being utilized, a composite sample proportioned to flow shall be prepared from individual grab samples.
** Report both influent and effluent flow, even if only one flow measuring device is installed.

Table VI-3 - Effluent Monitoring Requirements (Outfall 001C if not stated as other outfall)

Parameter	Measurement Frequency	Sample Type
Effluent Flow, MGD		
Outfall 001C	Continuous	Recorder **
Outfall 003A	Continuous	Recorder
Effluent $CBOD_5$, mg/l, Outfalls 001C and 003A	Daily	24-Hour Composite
Effluent Total Suspended Solids, mg/l, Outfalls 001C and 003A	Daily	24-Hour Composite
Effluent E. Coli., no./100 ml, Outfalls 001C and 003A	Daily	Grab
Effluent Total Residual Chlorine, mg/l		
Outfall 001C		
DPD method	4X/Day	Grab
Amperometric titration	Daily	Grab
Outfall 003A, DPD Method	Daily	Grab
Effluent pH, s.u., Outfalls 001C and 003A	Daily	Grab
Effluent Oil & Grease, mg/l, Outfalls 001C and 003A	Daily	Visual ***
Cyanide, Weak Acid Dissociable, ug/l	Weekly	Grab
Effluent Total Ammonia as N, mg/l	3X/Week	24-Hour Composite
Nitrate plus Nitrite, mg/l as N	3X/Week	24-Hour Composite
Dissolved Oxygen (minimum), mg/l	Daily	Grab
Arsenic, Total, ug/l	Quarterly	24-Hour Composite
Cadmium, PD, ug/l	Quarterly	24-Hour Composite
Chromium, Hex, Dissolved, ug/l	Quarterly	Grab
Copper, PD, ug/l	Weekly	24-Hour Composite
Iron, PD, ug/l	Weekly	24-Hour Composite
Lead, PD, ug/l	Quarterly	24-Hour Composite
Manganese, PD, ug/l	Quarterly	24-Hour Composite
Mercury, PD, ug/l	Weekly	24-Hour Composite
Nickel, PD, ug/l	Quarterly	24-Hour Composite
Selenium, PD, ug/l	Weekly	24-Hour Composite
Silver, PD, ug/l	Weekly	24-Hour Composite
Zinc, PD, ug/l	Quarterly	24-Hour Composite
Tetrachloroethene, ug/l	Monthly	Grab
Diazinon, ug/l	Monthly	24-Hour Composite
Whole Effluent Toxicity, Chronic	Monthly	3 Composites/Test

* If more than one source is being utilized, a composite sample proportioned to flow shall be prepared from individual grab samples.
** Report both influent and effluent flow, even if only one flow measuring device is installed.
*** If a visible sheen is noted, a grab sample shall be collected and analyzed for oil and grease. The results are to be reported on the DMR under parameter 03582.

2. Biosolids Monitoring

a. Biosolids Monitoring and Reporting: Facilities which practice or contract any methods of biosolids disposal, including beneficial use, landfilling, or any combination of disposal methods, are required to determine and report the annual rate of biosolids produced. Annual biosolids production and a description of biosolids disposal practices are to be included in the annual report. Please see Part I, Section D.3 of the permit for more information. Additional requirements apply if land disposal for beneficial use is practiced. (See Part I.A.9. and I.B.3. of the permit for specific requirements).

b. Land Application of Biosolids for Beneficial Use

The discharge of solid waste to land for disposal is regulated by the Colorado Solid Wastes Disposal Sites and Facilities Act (30-20, Part 1 C.R.S. 1973) Biosolids Regulations, Regulation Number 64, Section 30-20-102(6) of the Act provides an exemption from the Certificate of Designation requirement for biosolids which are used in a beneficial manner and where the disposal of such biosolids is designated as meeting all applicable regulations of the Department, including the Biosolids Regulations.

*The **Metro Wastewater Reclamation District treatment facility** is a "Treatment Works Treating Domestic Sewage" (TWTDS) as that term is defined in the Biosolids Regulations, 64.9. As such, the requirements of the Biosolids Regulations are applicable to biosolids produced at this WWTP and which are land applied for beneficial use. The requirements imposed in this permit will be consistent with the Biosolids Regulations. See Parts I.A.9 and I.B3. of the permit for specific requirements.*

There are pathogen reduction and vector attraction reduction alternatives, in addition to those identified in Part I.A8b) and c) of the permit which may be allowed per the Colorado Biosolids Regulations, 64.12.B and C. If the permittee intends to use one of these alternatives, the Division and EPA must be informed at least 30 days prior to its use. This change may be made without additional public notice.

Requirements of the Biosolids Regulations are in addition to the monitoring requirements noted above.

3. Pretreatment Program - The permittee has been delegated primary responsibility for enforcing against discharges prohibited by 40 CFR 403.5, and applying and enforcing any National Pretreatment Standards established by the Environmental Protection Agency in accordance with Section 307(b) and (c) of the Act.

As part of the pretreatment program, the permittee is responsible for an annual report describing their pretreatment activities over the previous calendar year. As part of the annual report, the permittee is responsible for influent and effluent sampling.

4. *Whole Effluent Toxicity (WET) Testing - Biomonitoring*

a. *Purpose of WET Testing: The Water Quality Control Division has established the use of WET testing as a method for identifying and controlling toxic discharges from wastewater treatment facilities. WET testing is being utilized as a means to ensure that there are no discharges of pollutants "in amounts, concentrations or combinations which are harmful to the beneficial uses or toxic to humans, animals, plants, or aquatic life" as required by Section 31.11 (1) of the Basic Standards and Methodologies for Surface Waters.*

b. *Instream Waste Concentration (IWC): Where monitoring or limitations for WET are deemed appropriate by the Division, chronic instream dilution as represented by the chronic IWC is critical in determining whether acute or chronic conditions shall apply. According to the Colorado Water Quality Control Division Biomonitoring Guidance Document, dated July 1, 1993, for those discharges where the chronic IWC is greater than (>) 9.1% and the receiving stream has a Class 1 Aquatic Life use or Class 2 Aquatic Life use with all of the appropriate aquatic life numeric standards, chronic conditions apply. Where the chronic IWC is less than or equal to (≤) 9.1, or the stream is not classified as described above, acute conditions apply. The chronic IWC is determined using the following equation:*

IWC = [Facility Flow (FF)/(Stream Chronic Low Flow (annual) + FF)] X 100%

The flows and corresponding IWC for the appropriate discharge point are:

Discharge Point	**Chronic Low Flow, 30E3, (cfs)**	**Facility Design Flow, (cfs)**	**IWC, (%)**
001	5.0	351.4	98.6

*The IWC for this permit is **98.6%**, which represents a wastewater concentration of **98.6%** effluent to **1.4%** receiving stream.*

c. *Chronic WET Limitations: The Metro Wastewater Reclamation District WWTF is a major wastewater treatment facility which has numerous commercial and industrial contributors. **It is Division's practice to include WET limits in permits for all major domestic facilities. Due to the large number of taps in all major facilities service areas, the likelihood that one or more dischargers to the collection system contributes toxic substances in toxic amounts is significant,** for this reason the Division believes there is reasonable potential for the discharge to interfere with attainment of applicable water quality classifications or standards. Because of this condition, the chronic limit has been incorporated into the permit and becomes effective **on the effective date of the permit**. The results of the testing are to be reported on Division approved forms. The permittee will be required to conduct two types of statistical derivations on the data, one looking for any statistically significant difference in toxicity between the control and the effluent concentrations and the second identifying the IC_{25}, should one exist. Both sets of calculations will look at the full range of toxicity (lethality, growth and reproduction). If a level of chronic toxicity occurs, such that there is a statistically significant difference in the lethality (at the 95% confidence level) between the control and any effluent concentration less than or equal to the Instream Waste Concentration (IWC) and if the lethality IC_{25} < the IWC, the permittee will be required to follow the automatic compliance schedule identified in Part I.B of the permit, if the observed toxicity is due to organism lethality. Once the chronic lethality limitation becomes effective, only exceedance of the limitation specified in Part I.A.5. will trigger the requirement for conducting the automatic compliance schedule identified in Part I.B. of the permit. Prior to and after the limitation becomes effective, if the toxicity is due to differences in the growth of the fathead minnows or the reproduction of the Ceriodaphnia, no immediate action on the part of the permittee will be required. However, this incident, along with other WET data, will be evaluated by the Division and may form the basis for reopening the permit and including additional WET limits or other requirements.*

d. *General Information: The permittee should read the WET testing sections of Part I.A. and I.B. of the permit carefully. The permit outlines the test requirements and the required follow-up actions the permittee must take to resolve a toxicity incident. The permittee should read, along with the documents listed in Part I.B of the permit, the Colorado Water Quality Control Division Biomonitoring Guidance Document, dated July 1, 1993. This document outlines the criteria used by the Division in such areas as granting relief from WET testing, modifying test methods and changing test species. The permittee should be aware that some of the conditions outlined above may be subject to change if the facility experiences a change in discharge, as outlined in Part I.D.4.e) of the permit. Such changes shall be reported to the Division immediately.*

e. *WET Test Method Modifications: The permittee has requested and will be allowed to make the following modifications to the WET test procedures:*
   1) *Use of testing in a CO2 atmosphere for control of pH creep;*

f. *WET Test Results Certification: The permittee has requested and the Division has agreed that the meaning of the term "accurate" as applied to whole effluent toxicity test results has the meaning as set forth in the U.S. Environment Protection Agency's memorandum, dated March 3, 2000, from Charles S. Sutfin et al. to Regional Water Management Division Directors, EPA Regions I-X and Regional Enforcement Division Directors, EPA Regions I-X, on the subject of Certification of "Accuracy" of Information Submissions of Test Results Measuring Whole Effluent Toxicity.*

C. *Reporting*

1. *Discharge Monitoring Report - The permittee must submit a Discharge Monitoring Report (DMR) monthly to the Division. This report will contain the test results for parameters shown in Tables VI-2 and VI-3 and Part I, Section B of the permit. The DMR form shall be completed and submitted in accordance with Part I, Section D.2 of the permit.*

2. *Annual Biosolids Report - The permittee will be required to submit an annual Biosolids Report which includes the results of all biosolids monitoring performed for the year and information on management practices, land application sites, site restrictions and certifications. The Annual Biosolids Report is due by* ***February 19th*** *of the following year. Refer to Part I, Section D.3 of the permit.*

3. *Special Reports - Special reports are required in the event of a spill, bypass, or other noncompliance. Please refer to Part I, Section D.4 of the permit for reporting requirements.*

D. *Additional Terms and Conditions*

1. *Signatory Requirements - Signatory requirements for reports and submittals are discussed in Part I, Section D.1 of the permit.*

2. *Compliance Schedules*

   a. *Disinfection System Study – On or before July 1, 2003, the permittee shall submit an evaluation of the disinfection system's ability to treat to the final E. coli. limits.*

Code	Event	Permit Citation	Due Date
21599	Submit a disinfection system capacity study AND, if the facility is not capable of achieving the E. coli. limits, the permittee shall request an amendment to the permit for the design and construction of upgrades of the disinfection facilities.	Part I.A.7.	7/1/03

   b. *Copper Study - In order to determine if influent copper concentrations can be controlled through control of industrial dischargers and other sources, the permittee shall submit a study identifying the feasibility of reducing wastewater copper concentrations.*

Code	Event	Permit Citation	Due Date
50199	Submit plan for study of influent copper concentrations.	Part I.A.7.	6/30/03

21599	*Submit study of influent copper concentrations and implementation plan to meet copper limits.*	*Part I.A.7.*	*3/31/05*

c. *Nitrate Study – During the period 10/1/02 through 9/30/03, the permittee will conduct 24-hour composite sampling for Nitrate + Nitrite (NO5) to determine if it can reliably meet the final permits limits with the existing facilities.*

On or before January 1, 2004, the permittee will submit a report on its ability to meet the final effluent limits with the existing facilities and request a permit amendment to include a compliance schedule for the design and construction of additional facilities if necessary to reliably meet the final permit limits.

Code	Event	Permit Citation	Due Date
21599	Submit a report on the WWTP's ability to meet the final nitrate plus nitrite effluent limits AND, if the facility is not capable of achieving the nitrate plus nitrite limits, the permittee shall request an amendment to the permit for the design and construction of upgrades of the facilities.	Part I.A.7.	1/1/04

d. *Dissolved Oxygen – To assure the instream dissolved oxygen standards are met, the permittee shall complete the following compliance schedule.*

Code	Event	Permit Citation	Due Date
21599	Submit a report describing the need for and proposed location of one or more dissolved oxygen drop structures between Brighton Ditch diversion and the Lupton Bottoms Ditch diversion (including the potential modification of the Lupton Bottoms diversion). AND Submit design and construction schedule for the recommended facilities. OR If the report indicates that additional drop structures are not needed, the permittee shall request the permit be amended to remove the requirement for further study of dissolved oxygen and construction of drop structures.	Part I.A.7.	9/30/03
03599	Submit a report of construction progress.	Part I.A.7.	9/30/04
09199	Completion of drop structure construction to point of operation.	Part I.A.7.	6/30/05
21599	Submit a report describing the need for and proposed location of dissolved oxygen drop structure(s) north of the Lupton Bottoms Ditch diversion. The Report shall describe the design and construction schedule for the recommended facilities. AND Submit design and construction schedule for the recommended facilities. OR If the report indicates that additional drop structures are not needed, the permittee shall request the permit be amended to remove the requirement for further study of dissolved oxygen and construction of drop structures.	Part I.A.7.	12/31/05
09199	Completion of drop structure construction to point of operation.	Part I.A.7.	9/30/07

E. Reopener, Permit Renewal and Fee Information

1. *The permit may be modified, suspended, or revoked in whole or in part during its term for reasons outlined in Part II. Section B.8 of the permit.*

2. *Requirements for permit renewal are discussed in Part II, Section B.9 of the permit.*

3. *Permit fee requirements are outlined in Part II, Section B.11 of the permit. An annual fee must be paid to the Water Quality Control Division to maintain the status of your permit.*

VII. REFERENCES

A. Colorado Department of Public Health and Environment, Water Quality Control Division Files.

B. "Design Criteria for Wastewater Treatment Works", Colorado Water Quality Control Commission, December 1994.

C. "Basic Standards and Methodologies for Surface Water", Regulation No. 31, Colorado Water Quality Control Commission, effective October 30, 2001.

D. "Classification and Numeric Standards South Platte River Basin, Laramie River Basin, Republican River Basin, Smoky Hill River Basin", Regulation No. 38, Colorado Water Quality Control Commission, effective January 30, 2002.

E. Colorado Discharge Permit System Regulations", Regulation No. 61, Colorado Water Quality Control Commission, effective June 30, 2002.

F. "Regulations for Effluent Limitations", Regulation No. 62, Colorado Water Quality Control Commission, effective December 30, 1998.

G. "Pretreatment Regulations", Regulation No. 63, Colorado Water Quality Control Commission, effective August 30, 2000.

H. "Biosolids Regulation", Regulation No. 64, Colorado Water Quality Control Commission, effective March 1, 2000.

I. "Colorado Total Maximum Daily Load and Wasteload Allocation Guidance", Colorado Department of Public Health and Environment, Water Quality Control Division, effective November 1991.

Lynn Kimble, P.E.
September 27, 2002

VIII. PUBLIC NOTICE COMMENTS

During Public Notice comments were received from Metro and EPA.

EPA commented that, 'The temporary modification for the Selenium (cr) water quality standard expires on 12/31/04, which is within the term of the permit. The permit/rationale should condition that if the underlying standard becomes effective, the facility needs to determine if they can comply with the standard and submit a compliance schedule if appropriate.'

The chronic selenium limit included in the permit is equal to the underlying selenium standard. For this reason, this discharge can not cause or contribute to an exceedance of the underlying selenium standard and no change has been made to the permit with regards to selenium.

EPA commented that, 'There were monitoring requirements for influent and effluent diazanon in the previous permit as well as a limit for tetrachloroethene in the effluent. The renewal permit needs to continue these requirements unless there is justification for dropping the requirements. Please provide an explanation in the rationale.'

Because Metro has provided data that the discharge does not present a reasonable potential to cause or contribute to an exceedance of the tetrachloroethene standard, no permit limit will be included in the permit for tetrachloroethene. Monthly routine monitoring have been added to the permit and rationale.

Metro provided comments regarding the power generation from the gas from this anaerobic digestion and biosolids production.

These comments have been incorporated into the facility description.

Metro has requested that the effective date of the permit copper limits be changed from January 1, 2005 to April 1, 2005 and that the description of the copper study compliance schedule be modified.

This change has been made in the permit and rationale.

Metro requested that the language of Part I, C. 5. of the permit be altered to specifically refer to monitoring at locations consistent with permit monitoring requirements.

This change has been made to the permit.

Metro requested that further definition of the WET certification statement be included in the rationale.

This language has been included in the rationale.

Metro requested that the pretreatment language on the rationale be altered to more representatively portray the pretreatment annual report.

This language has been reworked.

Metro requested that during flood events that the District be allowed to alter effluent monitoring points and forgo dissolved oxygen monitoring.

Because discharges during flood events are not anticipated to cause or contribute to exceedances of the stream standards, and because a failure to alter these requirements would cause a risk to the lives of the samplers, these changes have been made to the permit.

Metro has requested that the language in footnote c/ be altered to more closely represent the terminology utilized in E. coli testing.

These changes have been made.

Metro has requested that a footnote w/ be added to define the sampling and monitoring procedures for the Metro facility.

This footnote has been added.

Metro has requested that chlorine monitoring and reporting procedures included in the previous permit be continued in this permit as footnote t/.

This footnote has been included in the permit.

Metro has requested that additional treatment options that are included in Regulation 64, Biosolids Regulation, be included in the permit.

These options have been added to the permit.

Tables in Part III of the permit were updated to reflect the current information in 40 CFR 122. This update included the addition of several toxic pollutants and the inclusion of 'Waste Combustors' as a categorical industry.

Typos identified during Public Notice were also corrected.

Lynn Kimble, P.E.
December 20, 2002

Records Organize Go To Exit 8:43:42 amID 144040
AREA 2 DE_AREA 4
PWS_TYPE C TYPE_CHGDT / /
SOURCECODE G SRC_CHG_DT / /
COUNTY 044 CO_NAME Morgan
CO_FIPS NAME Morgan Heights W&S
DBA_ALIAS Morgan Heights W&S C_ADDR
C_ADDR2 21 Cooper Ct C_CITY Ft Morgan
C_STATE CO C_ZIP 80701
VITAL_INFO C.Gail Huner (303)447-1238
VITAL_INF2 All wells are off line, system using 100% purchased water from Ft VITAL_INF3
Morgan 144005 thru the end of winter. 2001 FAX_NUMBER
E_MAIL CONTACT Bill Hamlin
C_PHONE 9708678543 OPERATOR Powell, Walt
PHONE (970)867-1659 FNAMEBIZ
LNAMEBIZ TITLEBIZ
PHONEBIZ ACT_FLAG A
ACTCHGRESN A_I_DATE /
SYS_BEGIN / BACT_LAB NCHD
REQD 1 COMP_CYCLE M
POP_SERVED 194 N_TRAN_POP 0
TRANS_POP 0 SERV_CONCT 47
SEASON_BEG SEASON_END
ALT_REQSAM OWNER_TYPE L
TYPE_CODE Edit ‖K:\INV ‖Rec 2543/3658
‖File‖ ‖ Num

Basis for Permitting

The CDPHE Water Quality Control Division will make decisions regarding permits with reference to the assessment information given above. It is not possible to anticipate exactly how these decisions will be made, but some likely possibilities and principles are as follows.

Limits Based on Conditions in Segment 15 Below Sand Creek

The first requirement for effluent limits of any individual discharger is that these limits be based on firm assumptions about the allowable limits for all other dischargers such that the mixed flow below Sand Creek on Segment 15 of the South Platte River meets the water quality standards for Segment 15, except in the two cases where source waters exceed standards (fecal coliform, total recoverable iron). For the allocation strategy that is outlined in this assessment document, the relevant effluent limits are given by Table 6 for all five discharges. Alternate allocation schemes are possible if a discharger is willing to accept a more stringent effluent limit as a means of creating assimilative capacity that can be used by another discharger. In such a case, the assessment model should be used to find the exact balance of effluent limits under a revised allocation scheme that would be consistent with compliance for the mixed flow in Segment 15 below Sand Creek. A revised allocation scheme would result in a table with the same format as Table 6 but with differing effluent limits for substances that are subject to reallocation.

Lower Sand Creek

From the Division's point of view, it is important to know whether or not Sand Creek becomes fully mixed prior to reaching the South Platte River. Even if the regulatory mixing zone extends to the mouth of Sand Creek, as may be the case, actual mixing of the stream above the confluence with the South Platte likely would cause the Division to cap effluent limits based on the mixture of low flow and effluent within Sand Creek, if such limits were more restrictive than the ones imposed as a result of the need for compliance on the South Platte below Sand Creek. No mixing zone study has demonstrated whether or not full mixing occurs.

The assessment modelling included identification of standards for Sand Creek that would be exceeded if the effluent limits for the refineries were set according to requirements of Segment 15 mixed flow rather than standards applicable to Sand Creek (Table 8). The first two of these standards are total recoverable iron and fecal coliforms. Exceedance of these standards in Sand Creek is unavoidable because the background conditions are above standard. Therefore, the appropriate effluent limit for the dischargers is equal to the standard and there is no need for any special consideration of mixing or other factors.

The acute and chronic mercury standards also are exceeded in Sand Creek if the dischargers are limited by the requirements for the South Platte main stem. The predicted exceedance for acute mercury concentrations is trivial, however, in that it is less than 1% and therefore is not a likely cause for additional restrictions on effluent limits. For mercury under chronic conditions, there is a large discrepancy between the standard and the predicted value if limits for the refinery discharges are set according to requirements for the main stem. This discrepancy is explained by the fact that the main stem standard is for protection of aquatic life and the Sand Creek standard is for fish consumption.

There are a couple of possibilities for dealing with this discrepancy, and these need to be worked through by the dischargers under review from CDPHE. Given that consumption of fish from Sand Creek is extremely unlikely, the dischargers could request and provide justification for a change in the standard to reflect the protection of aquatic life rather fish consumption. This would require a series of steps under direction from WQCD. A second possibility is that the dischargers might choose to accept a permit limit near 0.01 µg/L, on grounds that mercury has not been detected and probably will not be detected in their effluent (the standard is far below the detection limit).

Another standard at issue for lower Sand Creek is selenium. Selenium is unusual in its treatment by this assessment in that the effluent limits were set according to predetermined concentrations that are incorporated into a negotiated agreement involving the dischargers and WQCD. The concentrations represented in this negotiated agreement lead to an exceedance of the chronic standard for selenium in lower Sand Creek (Table 8). Because of the existence of the negotiated agreement, however, the adjustment of effluent limits for permitting purposes is unlikely. The situation may change, however, when selenium standards are revisited by the State.

The listings in Table 8 for Sand Creek are based on modelling conditions for compliance in the main stem, which means that the low flows for Sand Creek were assumed to be equal to those consistent with low flow in the main stem. These low flows were obtained by difference (DFLOW in the main stem below Sand Creek minus DFLOW in the main stem above Sand Creek) rather than direct application of the DFLOW algorithm to flows at the mouth of Sand Creek. If the Division wished to view Sand Creek in isolation from the main stem, a stricter approach would be compute DFLOW values for Sand Creek itself, determine which standard would be exceeded if the effluent limits were as specified in Table 6, and then adjust the limits for these substances downward until compliance is achieved in Sand Creek. Table 9 summarizes the results of such a set of calculations.

Table 9 indicates exceedances for the five standards already mentioned. In addition, however, Table 9 lists aluminum, chromium VI, and residual chlorine. The expected exceedances by use of the stricter approach for calculating low flows is very small. The effluent limits for the Sand Creek dischargers can be reduced slightly from those of Table 6 to bring Sand Creek into compliance with the stricter assumptions for low flows in Sand Creek. These adjusted effluent limits are listed in Table 9.

Downward adjustment of the Sand Creek effluent limits for the Sand Creek dischargers results in additional assimilative capacity in the main stem. Because of the very small size of the downward adjustments, however, and the small amount of flow of Sand Creek relative to Metro's flow, additional assimilation capacity created in this way is negligible and need not be factored into effluent limits for Metro.

The Xcel Cherokee Discharge

The proximity of the Xcel Cherokee discharge to the Metro discharge and the width of the South Platte River over this reach indicate that full mixing of the Cherokee discharge with the receiving water is unlikely, even at low flow. Therefore, even in the absence of a site-specific study, it seems reasonable to assume that limits for Cherokee can be set on the basis of requirements for compliance with standards at the point of full mixing for all effluents below Sand Creek. If this is the case, restrictions on the Cherokee effluent will be set on the basis of criteria used in establishing Table 6, or any modification of Table 6 based on reallocation, and not on the basis of conditions that prevail on the South Platte between the Cherokee discharge and the Metro discharge.

Overview

In overview, Table 6 could be a reasonable basis for permitting all discharges under current conditions. Table 6 also could be modified for purposes of reallocating assimilative capacity subject to the same constraints that were used in the present version of Table 6. Table 9 can be used as an overriding supplement to Table 6 if the Division decides to treat Sand Creek separately from the main stem.

Constituent	Predicted[1]	Standard	Revised Effluent Limit[2]
Aluminum (Acute)	868	750	1230
Chromium VI (Acute)	18.4	16	26
Iron (Trec, Chronic)	1648	1000	N/A[3]
Mercury (Acute)	2.8	1.4	2.3
Mercury (Chronic)	0.34	0.01	0.027[4]
Selenium (Chronic)	26.8	12	N/A[5]
Benzene (Acute)	6060	5300	8740
Fecal Coliform (Acute)	233	200	N/A[3]
Residual Chlorine (Acute)	21.4	19	28

[1]Predicted with effluent limit as shown in Table 6.
[2]As necessary to meet standard with Sand Creek treated independently.
[3]No revision; source exceeds standard, use Table 6.
[4]Standard probably inappropriate.
[5]Limit set by negotiated agreement (60μg/L).

Table 9. Exceedances that would occur in Sand Creek with refinery effluent limits as shown in Table 6 but with stricter low flow assumptions (independent low flow analysis for Sand Creek), and effluent limits needed to eliminate exceedances under these stricter conditions.

Appendix B

Supplement to the South Platte River Segment 15 Water Quality Assessment
Reallocation of Assimilative Capacity for Selected Constituents

Prepared by: William M. Lewis, Jr.
James F. Saunders, III
Date of preparation: May 24, 2001

R/141

Introduction

This report is a supplement to the water quality assessment of Segment 15. The assessment report gives effluent limits for five point-source discharges that are mixed in Segment 15 below Sand Creek. Effluent limits were determined according to the following principles: (1) Effluent limits for the Metro District's discharge were set equal to the stream standard, except for selenium, which was set according to a negotiated agreement, and (2) effluent limits for the three refinery discharges and for the Xcel Cherokee discharge were all set to the same value (except where source water concentrations exceeded the standard); the common value for these four discharges was adjusted by use of the Assessment Model to achieve standards in Segment 15 just below Sand Creek. Thus, the allocation of assimilative capacity was done on the basis of equal use of assimilative capacity for the four dischargers other than Metro.

After reviewing the assessment report, the dischargers proposed some voluntary reallocation of assimilative capacity for selected constituents. The purpose of this voluntary reallocation is to take advantage of the capability of certain of the discharges to meet stricter effluent limits than would be required by the equal allocation principle.

The proposed voluntary reallocations were analyzed by use of the Assessment Model.

Iron (Total Recoverable, Chronic)

The Conoco refinery has two discharges (002 and 003). One of the discharges

(003) involves the treatment of groundwater, which is high in iron. Conoco and the other dischargers proposed an exchange of assimilative capacity consistent with requirements for meeting the iron standard on the South Platte River below Sand Creek. The reallocation involves setting Conoco 003 discharge to 3200 μg/L, setting Xcel Cherokee and Metro to 900 μg/L, and leaving the other two refinery dischargers (UDS and Conoco 002) at 1000 μg/L. This results in an expected South Platte concentration below Sand Creek of 970 μg/L under chronic low-flow conditions. Sand Creek at the mouth would be expected to reach a concentration of 2086 μg/L (standard, 1000 μg/L; source water 1900 μg/L) under low-flow conditions consistent with main stem chronic low flows.

Manganese (Dissolved, Chronic)

A reallocation involving manganese involves setting Conoco 003 to 2300 μg/L and setting UDS and Conoco 002 to 745 μg/L. Xcel and Metro would be set to 375 μg/L. The result would be a manganese concentration in the South Platte of 385 μg/L under chronic low-flow conditions, as compared with a standard of 400 μg/L. The concentration under low-flow conditions in Sand Creek itself would be 552 μg/L, which would be in compliance with the standard, which is higher for Sand Creek (2618 μg/L).

Zinc (Dissolved, Acute)

A reallocation for zinc involves setting UDS to 500 μg/L and Conoco 002 and

003 at 250 μg/L. Xcel Cherokee then is set to 395 μg/L and Metro is set to 215 μg/L. Under these conditions, the South Platte reaches 213 μg/L under acute low-flow conditions below Sand Creek (standard, 215 μg/L). Sand Creek would be at 100 μg/L (standard, 379 μg/L).

Overview

The limits shown in Table 1 would override limits shown in Table 6 of the assessment report if the reallocation is accepted.

	Discharge					Receiving Water	
Constituent	UDS	Conoco 002	Conoco 003	Xcel Cherokee	Metro	South Platte*	Sand Creek
Iron (Trec) Chronic	1000	1000	3200	900	900	970	2086
Manganese (Dissolved) Chronic	745	745	2300	375	375	385	552
Zinc (Dissolved) Acute	500	250	250	395	215	213	100

* Below Sand Creek.

Table 1. Proposed reallocation for iron, manganese, and zinc, as explained in the text, μg/L).

Appendix C

Segment 15 Water Quality Model Recalibration for 2001 and Use of the Model in Support of Permitting for Ammonia, CBOD, and Dissolved Oxygen

Prepared by: William M. Lewis, Jr.
James F. Saunders, III
Date of preparation: July 15, 2002

R/154a

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Executive Summary

The Segment 15 Water Quality Model was revised, updated, and recalibrated for use in support of permitting for the Metro District's discharge to the South Platte River. All hydrologic components of the model were re-estimated with recent information. Modelling was extended beyond the end of Segment 15 for a distance of approximately 11 miles into Middle South Platte Segment 1 (to Road 28). Predictions for Middle South Platte Segment 1 are hampered by the unavailability of sufficient information on reaeration and hydrology, however. While steps are being taken to obtain the appropriate information, the current modelling results must be designated as provisional for Middle South Platte Segment 1. For Segment 15, new information on reaeration rates was used in revising estimated reaeration at structures and within reaches between structures. For the first time, the model was developed for predictions in all months of the year, and was calibrated for ammonia, CBOD, and nitrate as well as dissolved oxygen.

Because of changes in the metabolism of the river, data collected by the Metro District prior to 1995 could not be used in recalibration. Eleven suitable data sets were available for recalibration, however, and four of these were reserved ahead of time for validation of the recalibration. The seven sets used in recalibration were used in determining rates of photosynthesis and community oxygen demand. Community oxygen demand was divided into four components: nitrification, algal oxygen demand, CBOD, and SOD. Temperature corrections were used in adjusting site-specific median rates for each of these processes to ambient conditions on a particular day at a particular location.

Testing of the recalibrated model against the validation data sets showed excellent prediction capability for ammonia, CBOD, and nitrate, and good prediction capability for oxygen.

In application of the model to future conditions, effluent limits for the South Adams, Brighton, and Fort Lupton facilities were set at fixed values. For South Adams and Brighton the values were determined by agreement among Metro and the managers of these facilities. Concentrations of constituents in the Metro effluent then were adjusted as necessary to achieve projected compliance with acute and chronic standards for ammonia and dissolved oxygen (Table I). Modelling results for nitrate are presented in a separate report.

Some of the modelling must take into account interaction between water quality constituents that are subject to effluent limits. Specifically, total ammonia, CBOD, and dissolved oxygen in the effluent all are subject to effluent limits and all affect dissolved oxygen in the river, which is subject to stream standards. The strategy for setting effluent limits for these interacting substances depends on the degree to which their concentrations are correlated in the Metro District's wastewater discharge. A study of interactions showed that no correlation or other statistical relationship exists between any of these constituents. Therefore, the forecasting component of the model assumes that when appropriate limits are being derived for a particular constituent (such as ammonia) the values for all other constituents (e.g., CBOD, dissolved oxygen in the effluent) should be set at characteristic values rather than at effluent limits. The rationale behind this strategy is that the concentrations of the constituents are randomly associated and therefore should not be considered to have simultaneous extremes.

Concentrations of total ammonia in the Metro effluent as shown in Table I below are consistent with stream standards for unionized ammonia. The critical point for unionized ammonia falls approximately five miles downstream of the Metro District's outfall. Concentrations of unionized ammonia decline steadily from the critical point to the end of the segment and ammonia is present in very low concentrations through upper MSP Segment 1.

Total ammonia concentrations shown in Table I were evaluated for consistency with dissolved oxygen standards. The predicted dissolved oxygen concentrations fell slightly below the thresholds set by the acute and chronic standards in the month of July (just above and just below the end of Segment 15) and in August and September (in upper MSP Segment 1, not in Segment 15). Knowledge of reaeration rates and hydrology in this portion of the river is poor at present. Assuming that the predictions are correct, however, introduction of a small amount of oxygen by use of a structure or other means would be adequate to cause the projected oxygen concentrations to be above the standards throughout Segment 15 (South Platte between the Metro outfall and Road 28). Adequacy of a structure for compliance with oxygen standards in MSP Segment 1 is uncertain due to the limited documentation on MSP Segment 1. Thus, the effluent ammonia concentrations shown in the table are adequate from the viewpoint of unionized ammonia and dissolved oxygen, assuming that there will be some compliance schedules for a reaeration enhancement facility just above the Lupton Bottom ditch and remodeling of the Lupton Bottom structure, if reaeration rates and hydrologic features in that area as estimated in the model are confirmed by further field studies upstream. Near Metro, the greatest future need is for a better understanding settling of CBOD. If field studies show that the CBOD settling rate is being overestimated, an aeration structure just above the Fulton Ditch would likely be needed.

The effects of a new facility, designated the Lower South Platte Regional WWTP, also were modeled. This facility was represented in the model on the basis of criteria developed by Carollo Engineers. Operation of the facility was represented under conditions expected for year 2020 and the point of discharge for the facility was assumed to be at the so-called Highway 85 location, just downstream from Brighton. Changes in the discharge of other facilities resulting from the installation of the Lower South Platte WWTP were incorporated in the modelling.

The Lower South Platte WWTP would have little effect on concentrations of unionized ammonia and, at the assumed effluent concentrations (5 mg/L), raises no permitting issues either for itself or for other dischargers. The Lower South Platte WWTP is projected to suppress downstream oxygen concentrations by a few tenths of a mg/L, depending on month. This is a permitting issue only during the month of July, and only near and below the Lupton Bottom diversion, where concentrations slightly below the standards are projected to result from the Metro effluent with or without the Lower South Platte WWTP. The Lower South Platte WWTP thus is projected to decrease oxygen concentrations a few tenths below concentrations that would already be somewhat below the standard. Because the suppression effect is expected to be small, it can be offset by any reasonably effective reaeration facility that is introduced at a point near and just above the Lupton Bottom diversion. Thus, construction and operation of the Lower South Platte WWTP does not raise any unique problems for permitting related to unionized ammonia or dissolved oxygen.

	Concentration, mg/L					
	Total Ammonia N		CBOD		Dissolved Oxygen	
Month	Chronic	Acute*	Chronic	Acute*	Chronic	Acute*
METRO						
January	15.0	30.0	17.0	30.0	4.5	2.0
February	15.0	30.0	17.0	30.0	4.5	2.0
March	14.0	26.6	17.0	30.0	4.5	2.0
April	14.0	25.6	17.0	30.0	5.0	3.0
May	13.0	25.9	17.0	30.0	5.0	3.0
June	13.0	27.0	17.0	30.0	5.0	3.0
July	10.0	21.5	17.0	30.0	5.0	3.0
August	9.7	23.4	17.0	30.0	4.5	2.0
September	10.0	26.7	17.0	30.0	4.5	2.0
October	10.0	23.4	17.0	30.0	4.5	2.0
November	14.0	24.1	17.0	30.0	4.5	2.0
December	15.0	27.8	17.0	30.0	4.5	2.0
SOUTH ADAMS						
January	25.0	-	25.0	-	4.5	-
February	25.0	-	25.0	-	4.5	-
March	25.0	-	25.0	-	4.5	-
April	25.0	-	25.0	-	5.0	-
May	25.0	-	25.0	-	5.0	-
June	25.0	-	25.0	-	5.0	-
July	25.0	-	25.0	-	5.0	-
August	25.0	-	25.0	-	4.5	-
September	25.0	-	25.0	-	4.5	-
October	25.0	-	25.0	-	4.5	-
November	25.0	-	25.0	-	4.5	-
December	25.0	-	25.0	-	4.5	-
BRIGHTON						
January	25.0	-	25.0	-	4.5	-
February	25.0	-	25.0	-	4.5	-
March	25.0	-	25.0	-	4.5	-
April	25.0	-	25.0	-	5.0	-
May	25.0	-	25.0	-	5.0	-
June	25.0	-	25.0	-	5.0	-
July	25.0	-	25.0	-	5.0	-
August	25.0	-	25.0	-	4.5	-
September	25.0	-	25.0	-	4.5	-
October	25.0	-	25.0	-	4.5	-
November	25.0	-	25.0	-	4.5	-
December	25.0	-	25.0	-	4.5	-
REGIONAL FACILITY						
January	5.0	-	25.0	-	5.5	-
February	5.0	-	25.0	-	5.5	-
March	5.0	-	25.0	-	5.5	-
April	5.0	-	25.0	-	5.5	-
May	5.0	-	25.0	-	5.5	-
June	5.0	-	25.0	-	5.5	-
July	5.0	-	25.0	-	5.5	-
August	5.0	-	25.0	-	5.5	-
September	5.0	-	25.0	-	5.5	-
October	5.0	-	25.0	-	5.5	-
November	5.0	-	25.0	-	5.5	-
December	5.0	-	25.0	-	5.5	-
	5.0	-	25.0	-	5.5	-

*Acute limits are not necessary for the small dischargers.

Table I. Effluent limits for dischargers to Segment 15 that would be consistent with standards for Upper South Platte Segment 15, as shown by the Segment 15 Water Quality Model.

Introduction

The Segment 15 Water Quality Model was first prepared under direction of the Metro District during the 1980s for the purpose of evaluating objectively the requirements for compliance with oxygen standards in support of aquatic life in Segment 15 of the South Platte River. In various stages of development, the model has been reviewed by the Water Quality Control Division of the Colorado Department of Public Health and Environment (WQCD) and by the USEPA Region VIII (EPA). Numerous improvements have been made incrementally in the model through software changes that allow increasingly realistic treatment of processes that affect dissolved oxygen and through the use of new data gathered by the Metro District from its monitoring program as well as special studies that are designed to provide information on critical rates. Beginning in 1999, the model was adapted for use in predicting concentrations of unionized ammonia in the South Platte River.

Recent applications of the Segment 15 model include assessment of the need for and location of reaeration structures that are intended to offset oxygen depression within Segment 15. The model also has been used in forecasting the appropriate effluent limits for total ammonia discharged from the Metro District's Central Treatment Plant as necessary to control oxygen consumption by nitrification to a degree consistent with the oxygen standards for Segment 15. In addition, the model also was used in estimating the maximum amounts of total ammonia in the Metro District's effluent that would be consistent in the future with standards for unionized ammonia in Segment 15. For both oxygen and ammonia, the model accounts for interaction between the Metro District's effluent discharge and the effluent discharges of the South Adams Williams Monaco Wastewater Treatment Facility and the Brighton Wastewater Treatment Facility (Figure 1).

The Segment 15 Water Quality Model has been recalibrated several times. Recalibration, which often has coincided with upgrades in the capability of the model, is intended to serve several purposes. The model incorporates important rate estimates for biological processes (e.g., nitrification, respiration, photosynthesis) and physical processes (e.g., reaeration, travel time). Biological processes may change some through time, particularly following major changes in treatment practices, such as the introduction of dechlorination (1988) and partial nitrification (late 1990) of the Metro District's effluent. Physical processes also may change in response to high flows that reconfigure the channel. Thus, recalibration keeps the rate constants as realistic as possible. Recalibration allows new information from special studies, such as studies of reaeration, to be used in improving the validity of the model. Also, recalibration allows the modelling to be brought into line with any conventions that are newly adopted by the State for permitting.

The purpose of this report is to describe a recalibration and upgrade of the Segment 15 Water Quality Model for year 2001, with emphasis on prediction of compliance with standards for oxygen and unionized ammonia in the South Platte below Metro, and to apply the model in support of permitting. Although part of the recalibration work is routine, the recalibration also provides the opportunity for changing the model as needed to make it consistent with recent decisions made by WQCD, to

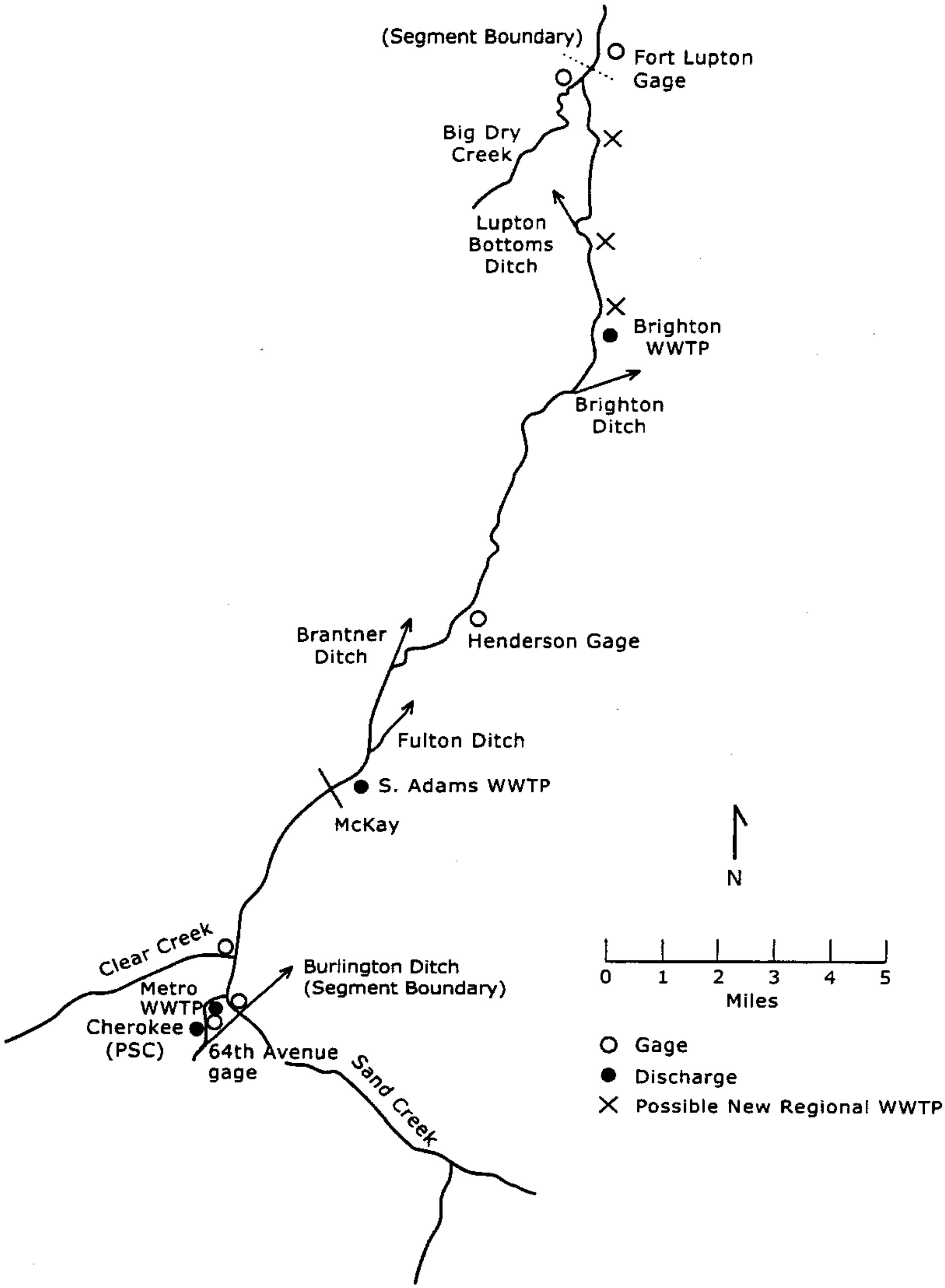


Figure 1. Map of Segment 15.

incorporate in the model physical changes in the river channel that have occurred since the last recalibration, and to introduce some improved methods of approaching certain modelling components, as explained in the sections to follow. One especially important feature of the 2001 calibration is increased emphasis on the lower portion of Segment 15 and middle South Platte Segment 1 (MSP Segment 1), just below Segment 15, down to Road 28 (Figure 2). In the past, because of regulatory emphasis on Segment 15, the focus of data collection, special studies, and modelling has been on Segment 15. This focus is now extending downstream, in part because of the natural progression of regulatory effort in the downstream direction through consideration of aeration structures in the lower half of Segment 15, and because of a provisionally-proposed Lower South Platte Regional Wastewater Treatment Facility, which would need effluent limits based on modelling of lower Segment 15 and upper MSP Segment 1.

Overview of the Model

The Segment 15 Water Quality Model depicts low-flow, steady-state conditions for each month of the year corresponding to the acute and chronic biologically-based low flows, which are the basis for permitting related to oxygen and ammonia. The software, which is incorporated into an Excel spreadsheet, includes recognition of the 24-hour cycles of photosynthesis, respiration, temperature, and pH, all of which are related to compliance with the oxygen or ammonia standards.

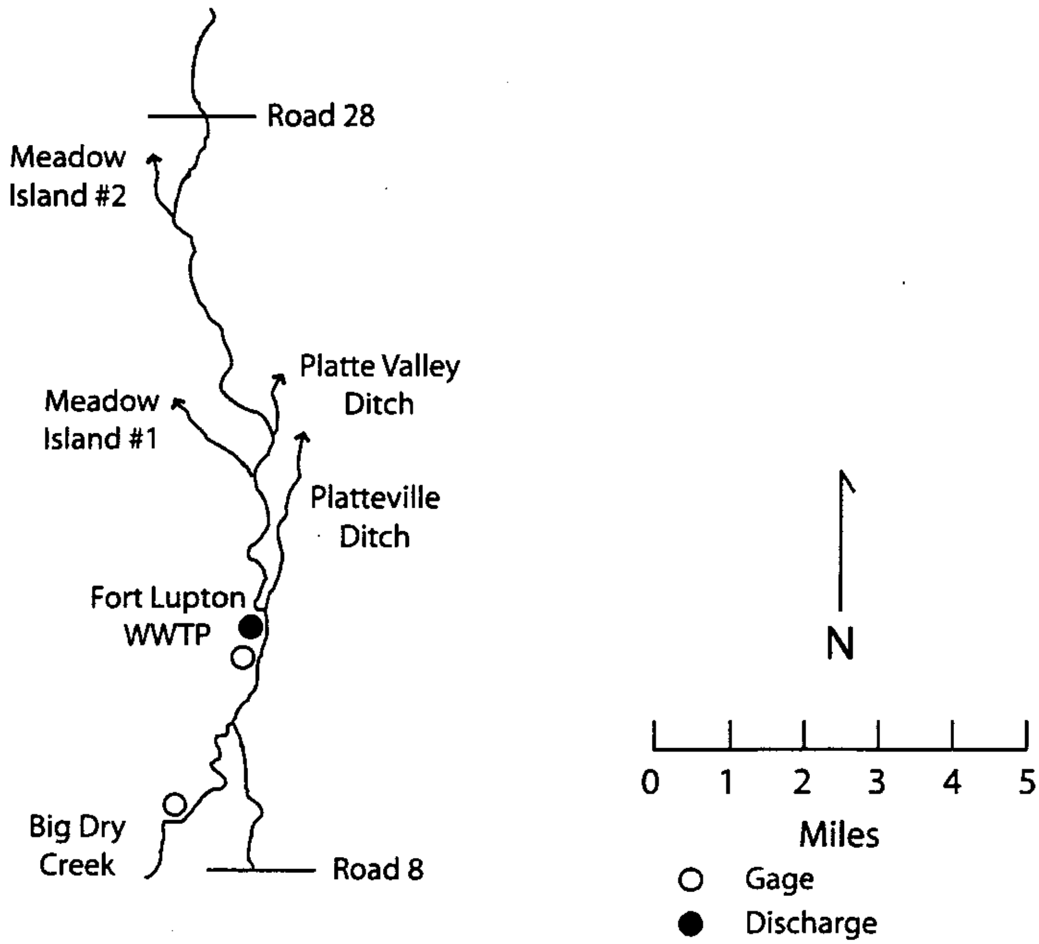


Figure 2. Map of middle South Platte Segment 1 down to Road 28.

The model makes use of field data in estimating changes in travel time and reaeration from one section of the river to another, and uses empirically-based rates for biological processes in each month of the year.

The model divides the modelling reach into 270 spatial increments. The length of a spatial increment never exceeds 0.5 miles, but shorter increments are used wherever a sudden change of water quality or flow is expected (e.g., at a tributary confluence, effluent outfall, etc.). A list of the locations of some landmarks is given in Table 1.

Each spatial increment in the model is treated as a processing unit (Figure 3). These units have an inflow at the upper end and an outflow at the lower end for water and for mass of the substances that are being modeled. Each of the increments shows a characteristic set of rates for physical and biological processes and each increment may receive flow of water or mass of a substance across its lateral boundaries through tributaries, effluent outfalls, or ungaged flows, and may lose water or mass through diversions. The outflow from any given increment constitutes the inflow for the next increment downstream.

When the model has been calibrated, it can be used in exploring the consequences of setting effluent limits of the Metro District's discharge or other discharges to any hypothetical concentrations. Thus, concentrations can be adjusted as necessary to predict compliance with oxygen or ammonia standards. Also, allocation strategies can be explored by adjustment of effluent concentrations when there is an interaction among two or more effluent discharges.

Monitoring and Special Studies

The Metro District monitors its two effluent streams (north, south) on a daily basis. Thus, there is a detailed record of Metro's effluent quality. While the record is

River Mile	Landmark Name
312.67	64th Avenue
312.20	Combined Outfall, Metro
312.10	Sand Creek
310.97	Clear Creek
310.16	78th Avenue
309.39	New Drop Structure
308.62	88th Avenue Drop
308.07	2nd Armored Crossing
306.41	McKay Road
306.37	South Adams Outfall
306.33	Relocated Fulton
306.22	Fulton Pool
305.77	Fulton Ditch
305.24	104th Avenue
304.67	Reaeration Structure #2
303.83	Brantner Pool
303.58	Brantner Ditch
301.08	Henderson Gage
300.98	124th Avenue
299.33	Reaeration Structure #4
297.02	Brighton Pool
296.74	Brighton Ditch
295.20	160th Avenue
294.70	Brighton Outfall
294.14	Great Western Site (Possible regional plant)
294.10	Baseline Road
291.85	Highway 85 Site (Possible regional plant)
291.83	Road 6
291.23	Lupton Bottoms Ditch
290.13	Road 8
289.63	North Wattenberg (Possible regional plant)
287.83	Big Dry Creek
287.19	Fort Lupton
286.22	Lupton WWTP
286.14	Pool
286.08	Platteville Ditch
283.69	Road 18
283.24	Meadow Island #1
282.62	Pool
282.59	Evans Ditch
278.57	Meadow Island #2
276.91	Road 28

Table 1. Locations of landmarks for water quality modelling.

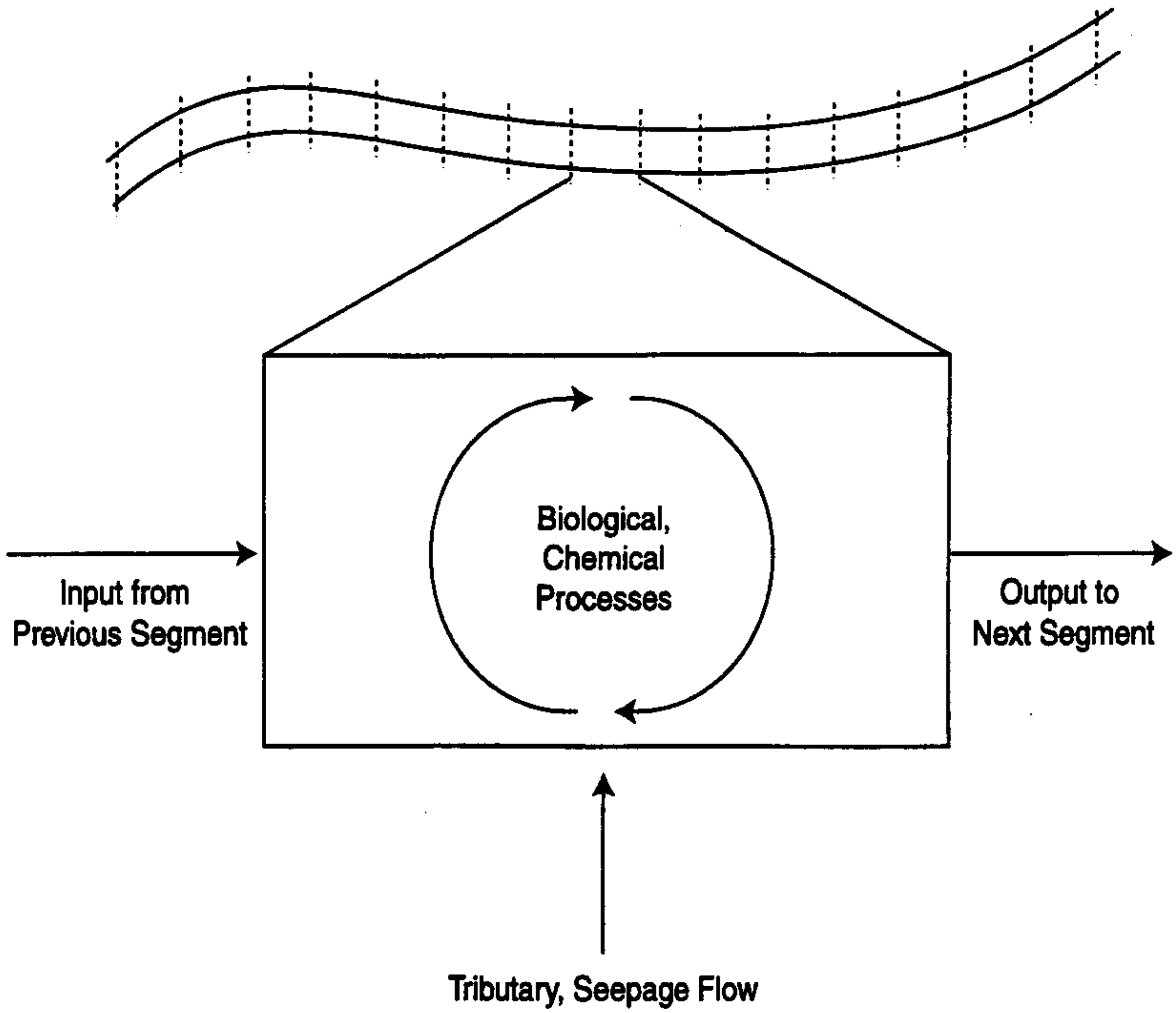


Figure 3. Conceptual view of the structure of the Segment 15 water quality model.

useful for certain purposes, such as demonstrating compliance with effluent limits, data on effluent quality are most useful if they coincide with studies of the river, as in the case of special studies (see below).

The South Platte is monitored biweekly by the Metro District throughout the year. Monitoring sites extend along Segment 15 and into MSP Segment 1 (Table 2). Analysis of chemical samples taken at the time of monitoring is extensive, but the constituents of

Biweekly Monitoring Sites on the South Platte River
64th Avenue Metro District Effluent Above Clear Creek 78th Avenue 88th Avenue McKay Road 124th Avenue 160th Avenue
48-Hour Studies, South Platte River Sites
64th Avenue Metro District Effluent 78th Avenue 88th Avenue 104th Avenue McKay Road 124th Avenue 160th Avenue Road 8 Fort Lupton Road 18 Road 28 Sand Creek Clear Creek Big Dry Creek

Table 2. List of sampling sites used by the Metro District in its biweekly monitoring and 48-hour studies.

direct concern to this recalibration include only total ammonia, pH, temperature, nitrate, dissolved oxygen, and CBOD.

The Metro District has conducted special studies of reaeration rates for various reaches of the South Platte and for particular structures in the river. Structures that generate strong turbulence or plunging flow may cause substantial reaeration over very short distances. The Metro District also has conducted studies of channel geometry, which is an important determinant of travel time and is used in converting volumetric rates to rates based on area.

One additional and especially important type of special study (diel study) conducted by the Metro District deals with 24-hour changes in temperature, pH, total ammonia, CBOD, and oxygen at several locations on the South Platte and its tributaries (Table 2); the studies are conducted over 48-hour intervals.

Hydrology and Low-Flow Analysis

The goal of the hydrologic component of recalibration is to estimate monthly acute and chronic low flows for the South Platte River between 64th Avenue and Road 28. The determination of low flows must be consistent with conventions that are used by the WQCD for issuance of permits.

The first step in the hydrologic component of recalibration is to quantify the amounts of ungaged flow that characteristically enter the South Platte during dry weather for each month of the year. A second step, which is accomplished by the combined use of gage records and estimates of ungaged flow, is to create an historical daily record of flow sufficient to support DFLOW analysis above and below each location where water is added or withdrawn (tributary mouths, effluent discharge points, ditch withdrawal points). A third step is to select and tabulate appropriate wastewater discharge volumes for use in modelling of future conditions. A fourth and final step is to use the information from the first three steps to estimate internally-consistent low flows for each month of the year under acute and chronic conditions in the future.

Estimation of Ungaged Flows

Ungaged flows may enter the South Platte River over the surface or underground. Dry-weather surface flows from small, ungaged tributaries and gulches have been documented for Segment 14 of the South Platte River, upstream of the Metro District's discharge. They appear to be less common below Segment 14, and have not been subjected to any rigorous analysis for Segment 15 or for MSP Segment 1. Subsurface flows (seepage) appear to be the main source of ungaged flow to Segment 15 and below. In the absence of documentation to the contrary, all of the dry-weather ungaged flow entering the South Platte between 64th Avenue and Road 28 is assumed to be seepage, and is assumed to enter the river channel in a spatially uniform manner. This is a simplification, given that the rate of seepage may not be uniform spatially. Seepage is expressed as cfs per mile of river.

Seepage estimates were made for three reaches: (1) 64th Avenue to Henderson, (2) Henderson to Fort Lupton, and (3) Fort Lupton to Road 28. The period of record for the upper reach extends from 01/31/92 to 09/30/00 (the Sand Creek gage record started on 1/31/92). The seepage rate was estimated as a flow residual, which was calculated as the difference between the Henderson and 64th Avenue gages, after accounting for daily additions from Sand Creek, Clear Creek, and the Metro and South Adams wastewater treatment outfalls and daily withdrawals by the Fulton and Brantner ditches. A plot of the residuals versus the flow of the South Platte at the 64th Avenue gage (Figure 4) shows that the residuals are relatively stable for flows less than 300 cfs at 64th Avenue, but not above 300 cfs. Therefore, residuals for flows higher than 300 cfs were excluded from the analysis.

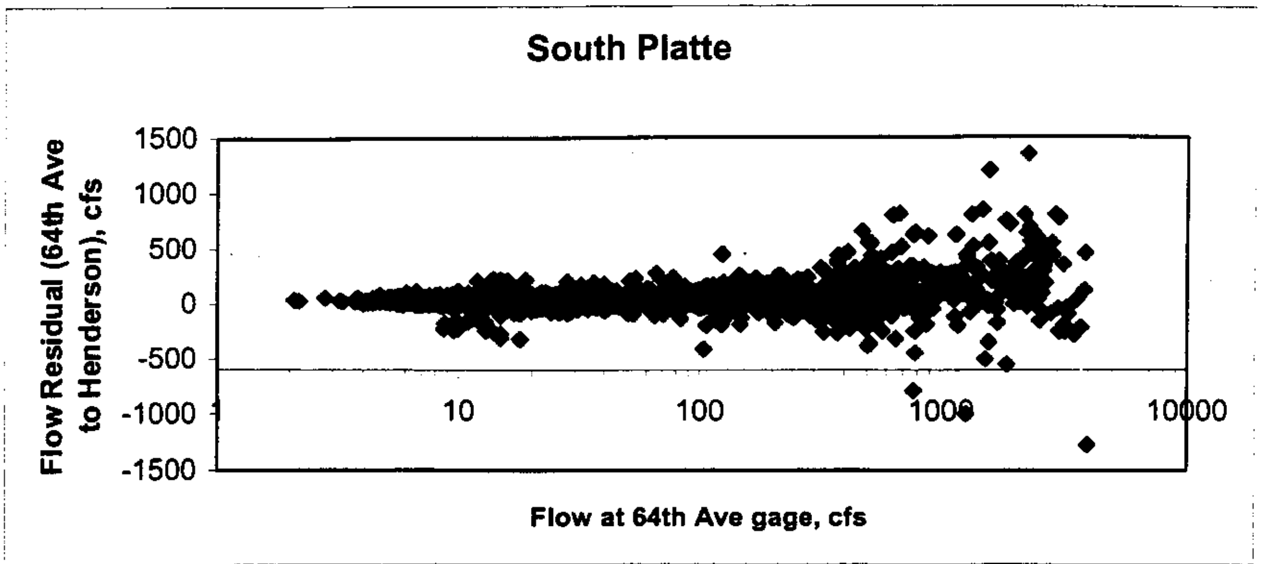


Figure 4. Daily flow residuals for the upper reach of Segment 15 (64th Avenue to Henderson) as a function of flow measured at the 64th Avenue gage.

The lower portion of Segment 15 was analyzed by a procedure very similar to that used for the upper reach. The period of record for flows extends from 10/01/91 to 9/30/96; the data set is constrained by limited overlap of operation for the Big Dry and Fort Lupton gages. The residual was calculated as the difference between the Fort Lupton and Henderson gages with adjustment for daily additions from Big Dry Creek and the Brighton wastewater treatment facility, as well as withdrawals by the Brighton and Lupton Bottom ditches. Daily residuals are shown in Figure 5 as a function of flow at the Henderson gage. Because 600 cfs marks the transition from stable to unstable residuals, seepage estimates were taken from records corresponding to flows less than 600 cfs at Henderson.

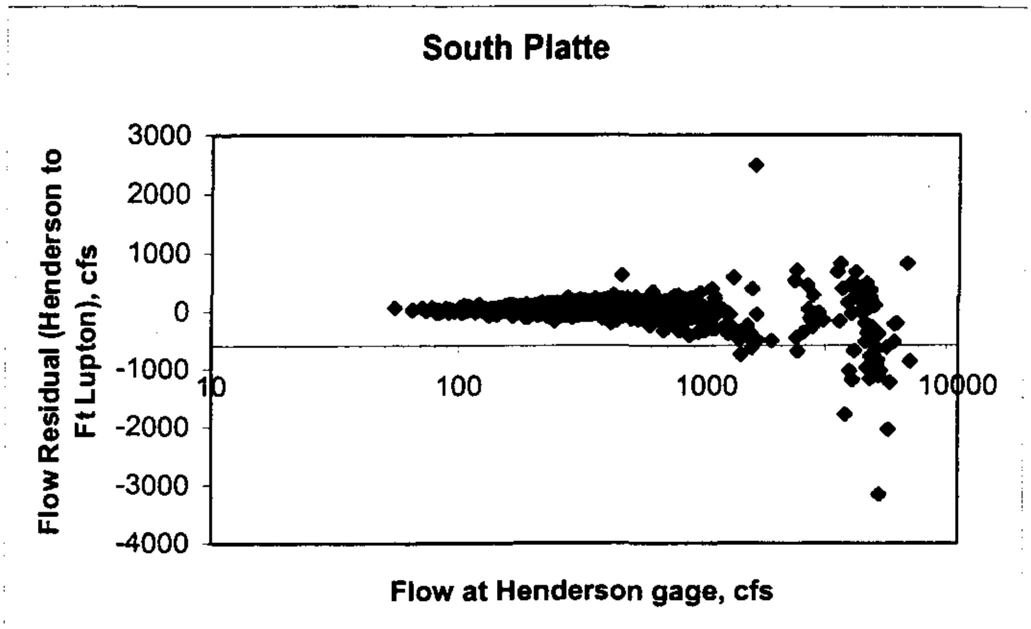


Figure 5. Daily flow residuals for the upper reach of Segment 15 (Henderson to Fort Lupton) as a function of flow measured at the Henderson gage.

The monthly values for ungaged flows are shown in Table 3. The ungaged flows of Table 3 are similar to those that were derived for previous modelling, but have a smoother seasonal pattern that probably reflects more accuracy for specific months.

Table 3 shows the ungaged flows only down to Fort Lupton, but the modelling extends downstream to Road 28. There is no gage that could serve as a basis for estimating residuals below Fort Lupton. For modelling it was assumed that seepage rates between Fort Lupton and Road 28 are set equal to the flows for the lower reach of Segment 15 times 2.5, as needed to reconcile with observed flows (any less would not provide enough water to fulfill observed ditch withdrawals).

Month	64th Avenue to Henderson	Henderson to Fort Lupton
Jan	2.56	2.34
Feb	2.71	1.23
Mar	2.30	1.60
Apr	3.23	2.55
May	3.49	4.72
Jun	5.16	3.16
Jul	4.42	3.92
Aug	3.32	2.42
Sep	4.09	2.52
Oct	3.60	3.12
Nov	3.64	2.56
Dec	2.97	2.12

Table 3. Median monthly seepage rates (cfs per mile) as estimated from daily residuals calculated for the upper and lower portions of Segment 15. Medians for the upper reach are based on days with flows less than 300 cfs at the 64th Avenue gage. Medians for the lower reach are based on days with flows less than 600 cfs at the Henderson gage.

Low-Flow Analysis for Historic Conditions

The simplest method of obtaining low flows under recent past conditions for all points on the South Platte between 64th Avenue and Road 28 would be to conduct a DFLOW analysis for each of the main stem gages and for gages on the two tributaries. Then, by use of the seepage rates and characteristic monthly values for ditch withdrawals and effluent additions, flows could be reconstructed for any location. The problem with this approach is that it assumes that biologically-based low flows occur simultaneously in the main stem and in the tributaries. Statistical analysis of flow records for Segment 15 has shown that this is not the case. Because of water management, low flows from tributaries do not occur simultaneously with low flows in the main stem. Furthermore, use of characteristic ditch withdrawals or effluent flows might not accurately reflect conditions at low flow. One final objection to the use of this approach is that it would produce low flows that are internally inconsistent, i.e., involving unexplained sources and losses of water.

An alternate method of obtaining acute and chronic low flows on a monthly basis for the South Platte River is to constrain the estimation of low flows around three factors: (1) the presence of specific amounts of ungaged flow, as estimated empirically from gaging station residuals; (2) gage records and effluent discharge records for specific points; and (3) the need for tributary flows and ditch withdrawals to be consistent with low flows in the main stem. This approach has been used previously under review from the EPA and the WQCD (TMDL for oxygen, South Platte River Segment 15; draft TMDL for nitrate, South Platte Segment 14).

The conditions listed above are satisfied through the use of daily flow records for the South Platte main stem above and below each tributary and each point of ditch withdrawal. For each month, the DFLOW value for South Platte River flow immediately below each tributary and each point of ditch withdrawal was subtracted from the DFLOW value for the same month on the South Platte River immediately above the same point of tributary flow or ditch withdrawal. Thus, the difference between the upstream DFLOW and the downstream DFLOW for any given month was the means for determining the flow for the tributary or ditch withdrawal that would be hydrologically consistent with empirically determined low flows on the main stem.

Low flows at the uppermost end of Segment 15 were determined recently as part of a water quality assessment involving Sand Creek and the upper end of Segment 15 of the South Platte River.[1] The low flows derived from the assessment reflect capacity effluent discharges to lower Sand Creek and to Segment 15 below the Burlington Ditch. The flows have been reviewed by the WQCD for consistency with future permitting practices. For the South Platte just above Metro, the low flow was derived from the daily flows on the South Platte just below the Burlington Ditch headgate plus the design flows

Month	Acute, cfs		Chronic, cfs	
	South Platte below Burlington Ditch**	Sand Creek above Refineries***	South Platte 64th Avenue	Sand Creek above Refineries***
Jan	1.0	10.1	5.0	16.0
Feb	1.4	12.6	5.0	14.9
Mar	1.0	11.8	5.0	14.9
Apr	2.8	14.5	5.0	20.1
May	4.8	13.3	5.7	28.0
Jun	1.9	12.3	5.7	23.0
Jul	1.7	4.0	6.0	15.0
Aug	13.0 *	42.0 *	5.5	19.0
Sep	1.0	11.6	5.0	16.0
Oct	1.0	13.1	5.0	16.0
Nov	1.0	11.8	5.0	16.4
Dec	1.2	8.9	5.0	15.0

* Forward averaging used by DFLOW4 can cause acute low flows to exceed chronic low flows.

** Add capacity flow of 8.5 cfs at Xcel Cherokee and a small amount of seepage to get flow just above Metro.

*** Add capacity flows of refineries to get flow at mouth of Sand Creek.

Table 4. Upstream low flows for modelling, as given in a recent water quality assessment (see text).

of the Xcel Cherokee plant and a small allowance for seepage. Due to some uncertainties in the flows, a minimum of 1 cfs was placed on acute low flows and a minimum of 5 cfs was placed on chronic flows below the Burlington Ditch. Details, including periods of record for flow analyses, are given in the assessment report. For Sand Creek, DFLOW

[1]South Platte River Segment 15 Water Quality Assessment. Analysis and Modelling in Support of Permitting on Lower Sand Creek and the Upper Portion of Segment 15, South Platte River. William M. Lewis, Jr. and James F. Saunders, III. May 24, 2001.

was calculated from the daily combined flows of the South Platte at 64th Avenue and flows of Sand Creek above the refineries. The DFLOW values at 64th Avenue for the same period of record were then subtracted to yield the appropriate low flows in Sand Creek above the refineries, and capacity flows of refineries were added to yield low flows at the mouth of Sand Creek. The net of these two values was then combined with the design capacity flows for the three refinery discharges to lower Sand Creek to yield the acute and chronic low flows at the mouth of Sand Creek.

Location	Basis for Calculation	Period of Record
Above Clear Creek	= 64th + Metro + Sand + seepage	01/31/92-09/30/00
Below Clear Creek	= Above Clear Creek + Clear Creek	01/31/92-09/30/00
Below Brantner	= Henderson – seepage	10/01/90-09/30/00
Above Brantner	= Below Brantner + Brantner	10/01/90-09/30/00
Below Fulton	= Above Brantner - seepage	10/01/90-09/30/00
Above Fulton	= Below Fulton + Fulton	10/01/90-09/30/00
Above Brighton	= Henderson + seepage	10/01/90-09/30/00
Below Brighton	= Above Brighton - Brighton	10/01/90-09/30/00
Above Lupton Bottom	= Below Brighton + Brighton WWTP + seepage	10/01/90-09/30/00
Below Lupton Bottom	= Above Lupton Bottom – Lupton Bottom	10/01/90-09/30/00
Above Big Dry	= Below Lupton Bottom + seepage	10/01/91-09/30/00
Below Big Dry	= Above Big Dry + Big Dry	10/01/91-09/30/00
Above Platteville	= Fort Lupton + seepage	10/01/86-09/30/96
Below Platteville	= Above Platteville - Platteville	10/01/86-09/30/96
Above Meadow Island #1	= Below Platteville + seepage	10/01/86-09/30/96
Below Meadow Island #1	= Above Meadow Island #1 – Meadow Island #1	10/01/86-09/30/96
Above Evans	= Below Meadow Island #1 + seepage	10/01/86-09/30/96
Below Evans*	= Above Evans – Evans	10/01/86-09/30/96
Above Meadow Island #2	= Below Evans + seepage	10/01/86-09/30/96
Below Meadow Island #2*	= Above Meadow Island #2 – Meadow Island #2	10/01/86-09/30/96

*A minimum value of 1 cfs is imposed on this location.

Table 5. Basis for calculating flows along the main stem of the South Platte above and below points of addition or withdrawal. Stations are listed in a sequence corresponding to the logic of calculation and may not reflect the geographic sequence. See text for explanation of seepage estimates.

There are two significant tributary flows and eight points of ditch withdrawal between Sand Creek and Road 28 (Table 5). The DFLOW analysis requires that daily flow records be created for points above and below each of these 10 points of addition and withdrawal. As shown in Table 5, the daily flows were reconstructed by combinations of gage records, recorded flows from effluent outfalls, recorded ditch withdrawals, and ungaged flows (seepage, estimated as described above).

The recommended record for DFLOW analysis, as determined by policies of the WQCD, is a recent, 10-year period of record for daily flows. As indicated by Table 5, this type of record is available only for a portion of Segment 15. Estimates of flow in the South Platte above and below Clear Creek are restricted to a shorter interval (approximately eight years) because the flow at this point requires use of data for the Sand Creek gage, which was not in operation until the end of January, 1992. For the South Platte at Big Dry Creek, the record is nine rather than 10 years because the Big Dry Creek gage was not installed until 1991. For points below Fort Lupton, use of the Fort Lupton gage is required, but operation of the gage was discontinued in 1996. Therefore, the most recent 10-year period of record is 1986 through 1996. Thus, the periods of record that were used in the low-flow analysis differ from one location to another. Nevertheless, a substantial range of overlap is available in all cases.

The validity of the flow reconstructions was tested by comparison of observed and reconstructed flows for the South Platte at the Fort Lupton gage. As indicated by Figure 6, the agreement between observed and expected is quite good ($r^2 = 95\%$). The slope of the relationship (0.93) suggests that predictions slightly overestimate the measured flows at the Fort Lupton gage.

Table 6 shows the flows of tributaries and withdrawals from ditches that are hydrologically consistent with the low flows in the main stem, as determined by the procedures described above.

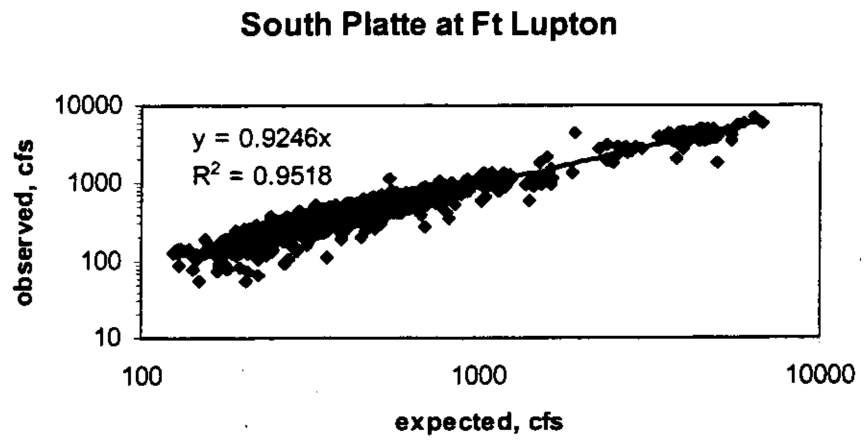


Figure 6. Comparison of measured flows at the Fort Lupton gage with flows at the same location reconstructed as flow below Big Dry and seepage (see Table 5) for the period of record 10/01/91 – 09/30/96. The data are displayed on log scales, but the regression line is linear.

Low Flows for Future Conditions

Low flows for future conditions were calculated from the low flows for historical conditions, developed as described in the preceding section, with the additional assumption that all effluent discharges will be increased to the design capacity at each point of wastewater discharge. Thus, the future low flows equal the historic low flows plus the increment of discharge between historic and capacity discharges. Increments of flow to reach capacity from each facility are assumed to carry to all downstream points of discharge, i.e., there is no flow reset above effluent outfalls downstream of Metro.

Table 7 shows the capacity discharges that were used in developing estimates of low flow for future acute and chronic conditions. Flows are shown monthly for Metro

Acute Low Flow

Month	Tributaries* Clear Creek	Tributaries* Big Dry Creek	Diversions* Fulton	Brantner	Brighton	Lupton Bottom	Platteville	Meadow Island 1	Evans	Meadow Island 2
Jan	24.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Feb	5.7	19.0	0.0	0.0	0.0	0.0	0.0	0.0	131.0	0.0
Mar	11.0	37.0	62.1	24.2	27.0	6.5	0.0	0.0	101.0	4.0
Apr	7.8	22.8	67.1	24.2	27.0	9.3	44.4	0.1	57.6	25.9
May	8.0	3.0	72.0	49.0	31.0	40.0	53.0	15.0	69.0	38.0
Jun	130.0	13.0	97.0	36.0	32.0	67.0	53.0	29.0	93.9	31.9
Jul	26.0	25.0	82.0	36.0	24.0	54.0	54.0	20.0	95.9	39.9
Aug	6.0	9.0	81.0	39.0	22.0	57.0	49.0	21.0	81.9	24.9
Sep	2.0	18.0	36.0	16.0	7.0	43.0	40.0	8.0	70.0	12.0
Oct	8.0	21.0	36.0	22.0	11.0	11.0	42.0	3.0	158.9	8.0
Nov	2.0	8.0	0.0	0.0	0.0	10.0	43.0	0.0	104.0	0.0
Dec	8.8	26.0	0.0	0.0	0.0	0.0	0.0	0.0	28.0	0.0

Chronic Low Flow

Month	Tributaries* Clear Creek	Tributaries* Big Dry Creek	Diversions* Fulton	Brantner	Brighton	Lupton Bottom	Platteville	Meadow Island 1	Evans	Meadow Island 2
Jan	15.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0	13.0	0.0
Feb	9.0	37.8	20.8	41.9	26.3	18.1	0.0	0.0	121.0	4.0
Mar	7.0	44.4	20.8	41.9	26.3	28.4	55.8	5.7	130.7	49.8
Apr	10.0	44.4	20.8	41.9	26.3	28.4	55.8	5.7	130.7	49.8
May	35.0	41.0	69.0	53.0	54.0	53.3	55.8	5.7	130.5	48.4
Jun	85.0	27.0	82.0	39.0	24.0	58.0	63.0	22.0	187.0	119.0
Jul	63.0	25.0	82.0	37.0	23.0	56.0	60.0	22.0	142.4	66.4
Aug	16.0	16.0	73.0	30.0	21.0	49.0	43.0	13.0	139.4	66.4
Sep	11.0	16.0	31.0	23.0	8.0	48.0	43.0	13.0	139.4	46.4
Oct	2.0	25.0	0.0	19.0	8.0	42.0	39.0	10.0	156.4	16.4
Nov	9.0	21.0	3.7	0.0	0.0	0.0	42.0	4.0	190.4	13.4
Dec	9.0	17.0	3.7	0.0	0.0	0.0	5.0	0.0	107.0	0.0

* Period of Record: WY91-WY00 for flows above Fort Lupton, except Clear Creek, which begins February 1992 and Big Dry, which begins October 91; WY87-96 for ditches below Fort Lupton.

Table 6. Monthly additions or withdrawals consistent with acute and chronic low flow conditions in the main stem of the South Platte.

and are annual values for other dischargers. Table 8 shows the estimated low flows for selected locations, and Figures 7 and 8 show the pattern of low flows for each month under acute and chronic conditions as a function of distance downstream from 64th Avenue.

Facility	Annual	Monthly											
		J	F	M	A	M	J	J	A	S	O	N	D
UltraMar Diamond Shamrock	0.5												
Conoco 002	0.82												
Conoco 003	2.16												
Cherokee	5.5												
Metro Combined		183.3	182.2	195.0	207.0	227.0	224.8	208.0	211.9	204.9	203.5	190.6	177.8
South Adams	7.0												
Brighton	3.0												
Fort Lupton	2.8												

Table 7. Design capacities (mgd) for WWTP's included in the Segment 15 Water Quality Model. Annual capacities listed for all discharges except Metro are for the maximum month across all months and are applied to every month of the year.

Figures 7 and 8 and Table 8 show that acute low flows exceed chronic low flows below the Evans Ditch in most months. Because WQCD uses the DFLOW4 algorithm in permitting, and the DFLOW4 algorithm is such that it is possible to find in some instances that the acute low flow exceeds the chronic low flow as determined by the DFLOW4 algorithm. This is explained by the fact that the DFLOW4 algorithm may be computing chronic low flows from a set of days that is mostly or entirely drawn from a month other than the one that is nominally the subject of analysis. This source of inconsistency is unlikely to extend across most months, however. Therefore, another explanation is likely in the present case.

Where low flows are smaller than the withdrawal capacity of a ditch, it is

Acute Low Flow (cfs)

	Tributaries		Diversions								Effluents	
Month	Clear Creek	Big Dry Creek	Fulton	Brantner	Brighton	Lupton Bottom	Platteville	Meadow Island 1	Evans	Meadow Island 2	S. Adams	Brighton
Jan	312.9	408.7	361.0	366.6	383.2	400.8	428.8	445.4	449.2	472.8	348.7	388.0
Feb	314.3	378.8	344.9	350.9	363.1	374.6	402.0	410.7	412.7	294.1	332.5	365.6
Mar	332.3	283.0	366.1	309.0	297.6	284.1	325.5	336.8	339.4	254.5	353.9	273.9
Apr	356.9	318.3	392.3	332.3	327.3	319.0	349.9	323.6	327.6	295.7	379.5	305.5
May	389.1	317.5	426.0	361.7	341.8	341.4	336.6	317.1	309.8	288.2	413.1	320.4
Jun	384.6	391.2	552.2	466.5	457.3	447.4	415.0	384.4	360.6	298.5	538.3	431.8
Jul	348.8	290.0	408.6	336.3	328.4	330.7	328.4	302.2	288.6	232.1	395.1	312.4
Aug	402.3	289.8	436.4	362.7	342.6	338.6	307.1	275.3	258.2	200.6	423.6	325.5
Sep	350.4	339.8	384.5	357.5	362.8	374.3	366.4	344.3	340.4	295.7	371.2	360.9
Oct	348.9	369.4	386.4	358.3	358.9	369.8	401.1	381.3	383.4	255.9	373.5	354.3
Nov	327.7	405.2	359.5	367.5	387.8	406.5	421.9	397.1	401.3	323.0	346.5	393.0
Dec	304.1	386.0	339.2	345.7	362.4	378.8	419.2	434.3	437.8	431.1	326.5	366.7

Chronic Low Flow (cfs)

	Tributaries		Diversions								Effluents	
Month	Clear Creek	Big Dry Creek	Fulton	Brantner	Brighton	Lupton Bottom	Platteville	Meadow Island 1	Evans	Meadow Island 2	S. Adams	Brighton
Jan	322.8	420.5	372.7	378.3	394.9	412.5	440.5	457.1	460.9	471.5	349.6	399.7
Feb	320.2	291.7	365.0	350.1	320.5	305.6	333.7	342.5	344.5	235.9	341.7	296.7
Mar	339.4	299.3	380.0	364.2	335.1	322.3	349.2	304.8	301.7	187.1	357.0	312.1
Apr	364.7	349.4	413.1	399.4	376.7	369.1	402.5	364.8	363.2	258.2	389.5	355.6
May	404.7	333.6	479.5	418.1	394.2	370.8	390.7	368.4	370.4	287.3	455.7	349.8
Jun	399.1	400.5	532.5	461.8	449.7	447.7	438.3	397.8	380.9	225.7	507.8	432.1
Jul	364.1	351.1	471.7	399.4	390.5	393.8	389.5	357.4	341.7	238.8	447.4	375.5
Aug	371.8	306.1	426.7	361.0	349.9	346.9	330.4	304.6	295.5	180.5	403.1	333.8
Sep	358.8	360.1	412.7	390.7	389.0	399.5	384.7	359.5	350.6	236.5	388.6	386.1
Oct	355.8	392.2	398.2	406.1	409.7	423.5	427.8	411.0	406.1	281.1	374.4	408.1
Nov	336.3	437.9	385.9	390.2	410.5	429.2	467.7	443.8	444.0	279.3	362.1	415.7
Dec	314.0	403.2	360.1	362.9	379.6	396.0	427.5	437.5	441.0	355.4	336.6	384.0

Table 8. Acute and chronic monthly low flows above each tributary, ditch, and effluent outfall assuming capacity flows at wastewater treatment facilities, based on application of the DFLOW4 algorithm as given in the text. Flows above Fort Lupton WWTP are the same as above the Platteville Ditch.

possible for the acute low flow to exceed the chronic low flow. Ditch withdrawals under acute conditions for the historical record, when the river flows

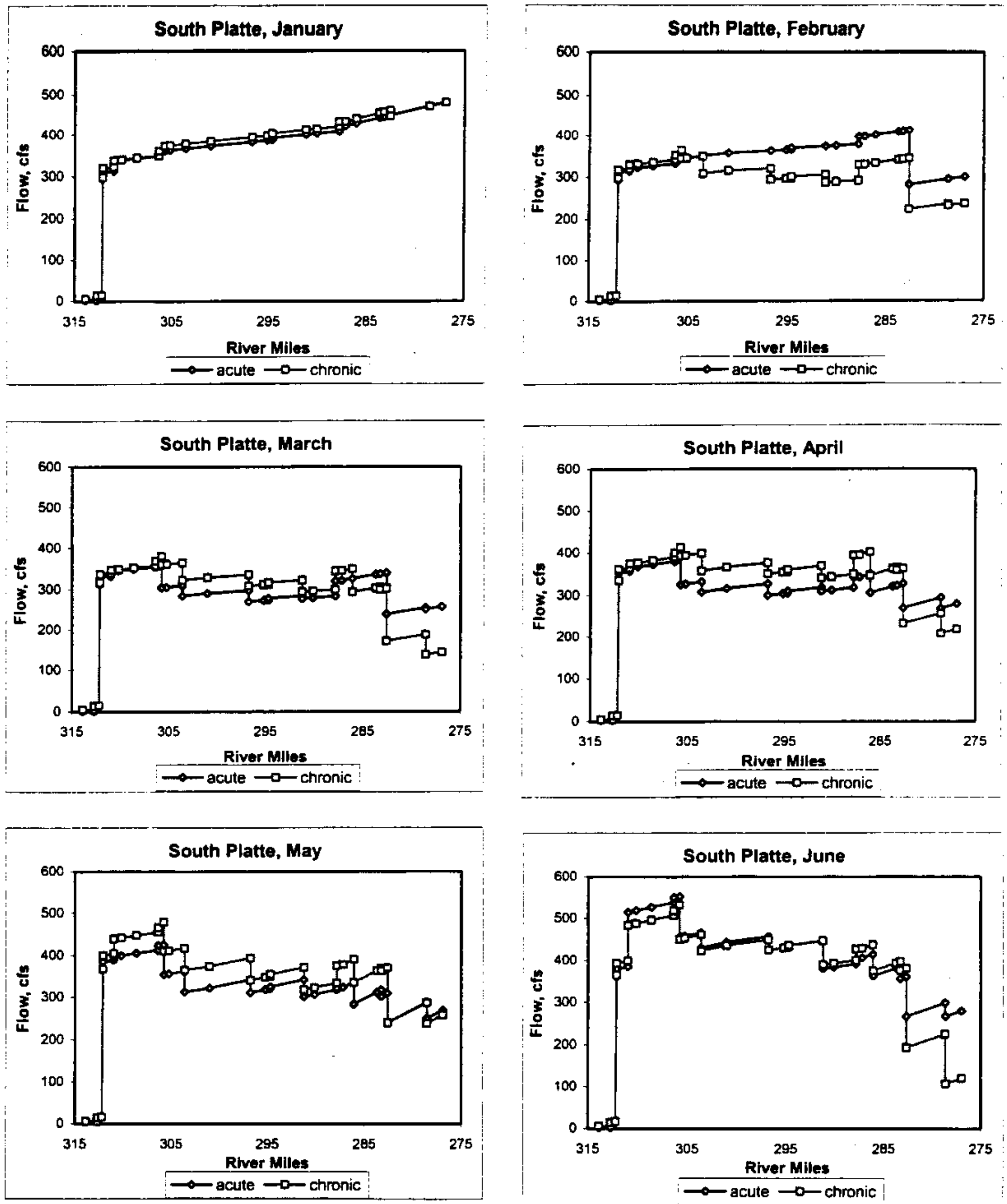


Figure 7. Low flows in the South Platte River with capacity wastewater flows, January – June.

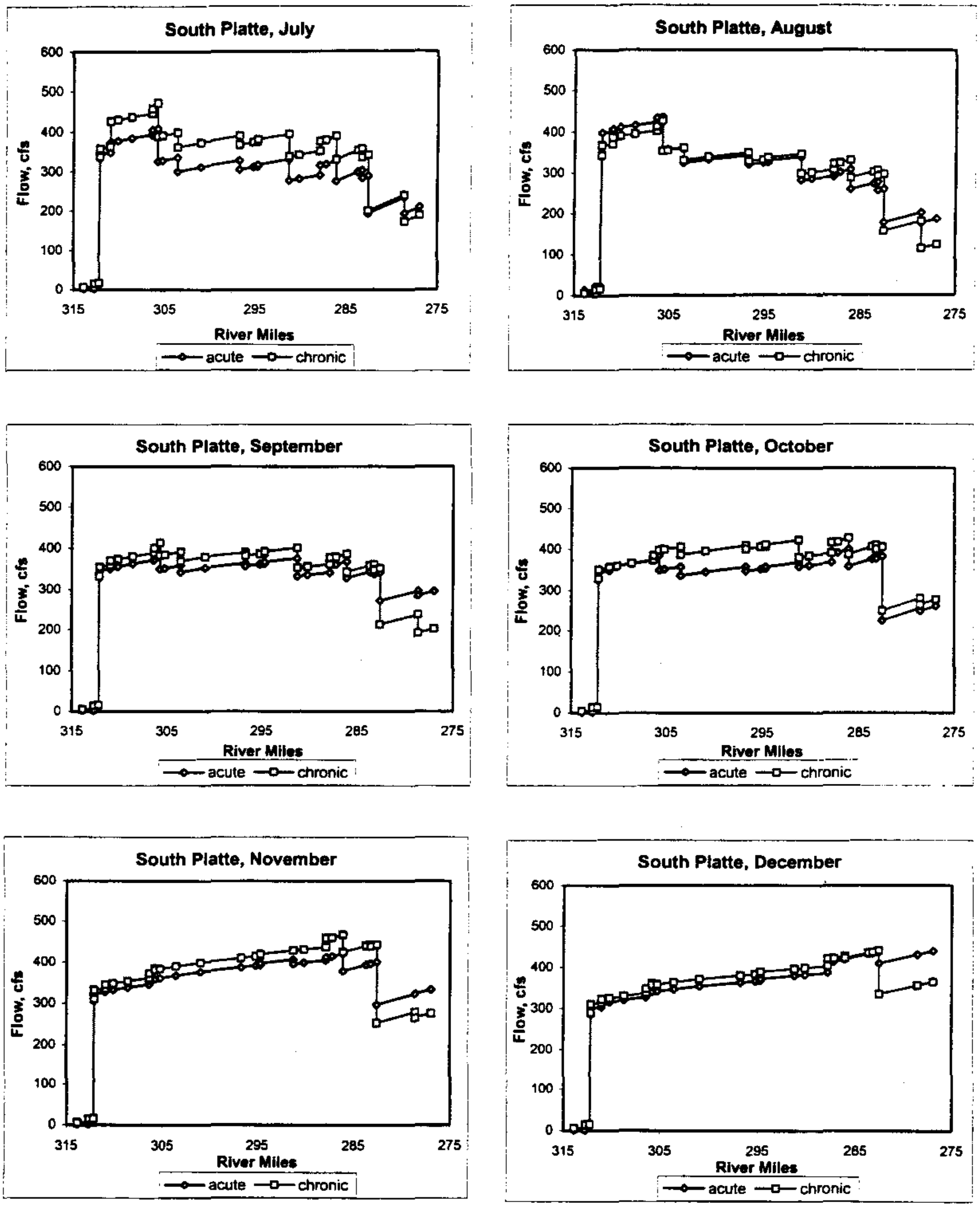


Figure 8. Low flows in the South Platte River with capacity wastewater flows, July – December.

are very low, may be small simply because the amount of water available for withdrawal is very low. Under chronic historic conditions of low flow, however, somewhat more water would have been available; therefore, the withdrawals could have been larger. In modelling future conditions, with the addition of increased flow from discharges upstream, the smaller withdrawals under acute conditions translate into higher flows in the main stem, and thus the projected acute flows can be larger than the chronic flows at and below points of major ditch withdrawal. In the present case, this anomaly appears to apply to the Evans Ditch and to the Meadow Island #2 Ditch.

Quality of Water Entering the River

Waters reaching Segment 15 and MSP Segment 1 include seepage flow, water entering the upstream end of Segment 15, tributary flows, and effluent discharges. Quality characteristics for low-flow conditions must be assigned to each of these flows. Water quality constituents relevant to modelling of oxygen and ammonia include pH, total ammonia, nitrate, oxygen, and CBOD. In addition, temperature must be estimated. For seepage flows, upstream flows, and tributaries, concentrations of constituents were estimated from monitoring data (Table 9). For modelling in support of permitting, future effluent quality must be anticipated. Some constituents are fixed at estimated values based on historically observed values or design characteristics, while others are left as free variables to be adjusted as necessary to achieve stream standards.

Seepage Water

During the 1990s, the Metro District supported collections of alluvial water from wells at McKay Road, Henderson, and Road 8 (1992-94: four wells with six or seven collection dates each; Table 9). This information can be used in estimating the chemistry of seepage water. In addition, USGS NAWQA program has collected alluvial samples (1992-95) in areas designated urban alluvial (four sites, one date each) and agricultural alluvial (three sites, one date each); these also can be used in the estimation of seepage water chemistry.

Two potential problems must be considered when alluvial well data are used to estimate seepage water chemistry. The first has to do with interchange of water between the channel and the hyporheic zone, which consists of permeable substrate (sand and gravel) that has an active hydrologic connection with water in the channel. Water within the channel penetrates the alluvium just beneath the channel, thus entering the hyporheic zone, and also moves from the hyporheic zone back to the channel. The pattern of entry and exit for such water is determined by water depth and contouring of sediments that make up the bed of the channel. In addition, it is possible for channel waters to penetrate the alluvium at the edge of the channel, thus flowing into the bank, and then return to the channel. In such a case, water that might be drawn from a shallow alluvial zone beside the channel would not constitute seepage water, but rather channel water that has temporarily entered the alluvial zone. It is important that alluvial wells represent water derived from the alluvium beyond the reach of the channel waters and not water temporarily entering the alluvium from the channel. Present sampling programs do not,

Sites	Period of Record	Variables (N of cases)	Comments
South Platte at 64th Sand Creek Clear Creek Big Dry Creek	1987-2001	Temperature pH D.O. CBOD Ammonia NO5	Daily average values from all diel studies (N=31 for Big Dry; N=32 for others). Mid-month temperature calculated from sine curve fit to observations for each site. DO based on % saturation. Special calculations for ammonia in Sand Creek.
Metro SFE	Jan 1996-Oct 2001	Temperature (2122) pH (154) D.O. (2117) CBOD (1120) Ammonia (141) NO5 (1197)	
Metro NFE	Jan 1996-Oct 2001	Temperature (1855) pH (145) D.O. (1854) CBOD (1122) Ammonia (134) NO5 (1048)	
South Adams Effluent	Jan 1996-Sep 2001	Temperature (1822) pH (1821) D.O. (1815) CBOD (772) Ammonia (258) NO5 (110)	Temperature and pH values replaced with data used in recent modelling for South Adams permit.
Brighton Effluent	Jan 1996-May 2001	Temperature (1975) pH (1975) D.O. (1965) CBOD (203) Ammonia (541) NO3 (147)	Temperature and pH values replaced with data used in recent modelling for South Adams permit.
Fort Lupton effluent	Jul 1999-Aug 2001	pH (26) D.O. (8) CBOD (26) Ammonia (26) NO3 (8)	DMR summary available only for Jul '99 thru Aug '01. Temperature set equal to that of Metro effluent. See text for assumptions used to set each variable.
Groundwater, USGS	1992-1993	pH D.O. Ammonia NO3	Four wells each at McKay, Henderson, and Road 8. Sampled on seven dates at Henderson, and six dates at the others. Temperature data not used.
Groundwater, NAWQA	1992-1995	pH D.O. Ammonia NO3	Four urban and three agricultural wells in the South Platte alluvium, each sampled on a single date.

Table 9. Sources of data used for recalibration of the Segment 15 Water Quality Model. The model uses monthly median values for most variables. Monthly median pH for most sites was calculated from monthly medians for temperature and % unionized.

however, provide validation of this requirement. Some recent studies of hydrology lower on the South Platte where seepage gains are very similar to those of Segment 15 and MSP Segment 1 do indicate that the entry of flow from the channel to the alluvium would be strongly suppressed by substantial hydraulic head between the alluvial waters and the channel waters under low flow conditions (Sjodin et al. 2001[2]). Thus, for present purposes it is assumed that the alluvial wells do in fact measure alluvial seepage water and not water that is secondarily derived from the channel. This assumption needs to be revisited in the future, however.

A second difficulty with the use of data derived from sampling of wells is that groundwater is much less subject to lateral mixing than surface water. Where factors influencing the chemistry of groundwater are heterogeneous, the groundwater itself can be expected to preserve this heterogeneity beneath the surface. The well sampling data do show considerable heterogeneity, even on relatively small scales of distance, in concentrations of critical constituents. Thus the ideal data set for estimation of seepage water chemistry would consist of many wells (e.g., one per half mile) rather than the relatively few wells that have been included in the relevant sampling programs. In this sense, the information on seepage water chemistry is less than ideal, but still useful.

The results of the well water analyses are summarized in Table 10, which lists five locations. The Burlington headgate area is identified with the USGS NAWQA wells classified as urban alluvial. The McKay Road, Henderson, and Road 8 are identified with the USGS sampling program on Segment 15 that was supported by the Metro District. The Platteville area is represented by the USGS NAWQA wells designated as

[2] Sjodin, A., W.M. Lewis, Jr. and J. F. Saunders, III. 2001. Analysis of groundwater exchange for a large plains river in Colorado (U.S.A.). *Hydrological Processes* 15: 609-620.

agricultural alluvial. The values listed in the table are medians of measurements for each location.

Location	pH	Ammonia, mg/L	Nitrate, mg/L
Burlington Headgate	6.8	0.10	3.00
McKay Road	7.1	5.30	0.01
Henderson	7.2	0.10	1.21
Road 8	7.1	0.10	8.58
Platteville	7.2	0.10	8.80

Table 10. Summary of median values for water quality data taken from alluvial wells.

For pH, the values as determined from Table 10 are little different from the ones that have been used previously for Segment 15 modelling (pH 7.2 for all locations), except that the Burlington area shows an unexpectedly low pH. Points geographically intermediate between those shown in Table 10 were assigned interpolated values in modelling.

Previously it has been assumed for modelling purposes that all alluvial water contains 4 mg/L of dissolved oxygen, which is generally representative of measured oxygen concentrations in alluvial water. Alluvial water must pass through the hyporheic zone, however, which is anoxic at low flow. Thus, seepage entering the river is assumed to have dissolved oxygen concentration of 0.0 mg/L.

In past modelling, it has been assumed that groundwater has an ammonia concentration of 0.1 mg/L. This amount, which is equal to the detection limit for standard analyses of total ammonia, is based on measurements of ammonia in alluvial water at various distances from the river. The alluvial sampling near the river, however, shows that there is substantial ammonia at well sites located in the upstream end of the modelling zone (Burlington to McKay). These observations show high variability, however, and thus are subject to considerable uncertainty. If incorrect, they will have a somewhat conservative effect on final results. For present purposes, the values shown in Table 10 are used and intermediate locations are represented by interpolated values.

Concentrations of nitrate in alluvial waters show high variation, even for wells that are located relatively close to each other. The values for McKay Road, Henderson, and Road 8 as shown in Table 10 indicate a steady downstream increase in the amount of nitrate; these values are used in modelling. For the Burlington area, there is considerable evidence, as obtained in a recent assessment,[3] that the nitrate concentration is near 3 mg/L. Thus, even though 3 mg/L is inconsistent with the trend between McKay and Road 8, it is used in modelling. Below Road 8, there is a large amount of inconsistency in concentrations, which range from very low to very high. Given the relatively small number of wells in this area, we use instead the results from a large number of wells surveyed by Gaggiani[4] (1984). The median for the survey was 8.8 mg/L. Interpolation was used in obtaining values intermediate between locations shown in Table 10.

Temperature for seepage water was assumed to be equal to the ambient temperature of stream water at any given location and time of year. This assumption is based on the fact that a temperature observed at any point in the stream in any given month reflects the contributions of upstream seepage water and that these effects will be to a large degree repetitive from year to year.

[3] South Platte River Segment 15 Water Quality Assessment. Analysis and Modelling in Support of Permitting on Lower Sand Creek and the Upper Portion of Segment 15, South Platte River. William M. Lewis, Jr. and James F. Saunders, III. May 24, 2001.

No data exist for CBOD in seepage; CBOD for seepage has been set arbitrarily to 2 mg/L for all reaches.

Effluent, Tributaries, and Upstream Flows

Temperature of effluents is measured with sufficient frequency to provide monthly medians at Metro, South Adams, and Brighton (Table 11). Temperatures for the other water sources are estimated by a variety of procedures. Temperature data for the three tributaries consist of daily averages from each of the diel studies conducted by Metro since 1987 (N=31 or 32). Diel studies have not been distributed evenly across months, and there have been no studies in some months. To establish a temperature for each month, a sine curve was fitted to the observations. The equation was used to predict

Month	64th	Metro combined	Sand Creek	Clear Creek	South Adams WWTP	Brighton WWTP	Big Dry Creek	Fort Lupton WWTP
Jan	6.3	15.6	4.7	4.4	11.1	10.6	2.7	15.6
Feb	7.1	15.3	5.8	5.5	13.3	10.0	4.1	15.3
Mar	9.4	16.0	8.6	8.3	12.2	11.1	7.5	16.0
Apr	13.3	16.6	13.0	12.6	14.4	14.4	12.5	16.6
May	17.3	18.4	17.5	16.9	16.1	17.8	17.5	18.4
Jun	20.5	20.1	20.9	20.2	18.9	17.2	21.3	20.1
Jul	21.9	22.0	22.3	21.6	22.2	20.0	22.7	22.0
Aug	21.3	23.0	21.3	20.7	22.2	20.0	21.4	23.0
Sep	18.6	22.7	18.2	17.6	22.2	19.4	17.7	22.7
Oct	14.9	21.0	13.9	13.4	17.8	17.2	12.8	21.0
Nov	10.8	18.9	9.3	9.0	12.2	12.2	7.7	18.8
Dec	7.7	16.6	6.0	5.7	13.3	13.9	4.1	16.6

Table 11. Temperatures used in the Segment 15 Water Quality Model.

[4] Gaggiani, N.G. 1984. Nitrogen, sulfate, chloride, and manganese in ground water in the alluvial deposits of the South Plate River valley near Greeley, Weld County, Colorado. Water-Resources Investigations Report No84-4088. U.S. Geological Survey.

temperature at mid-month for each of the sites. Table 12 shows the equations. Temperature for the Fort Lupton WWTP is available only as monthly minima and maxima in recent DMRs (Jan-Aug, 2001). Midpoints for the monthly temperature ranges are close to the monthly medians for the Metro combined outfall. Therefore, temperatures of the Fort Lupton effluent are set equal to the temperature of combined effluent from Metro.

Location	a	b	Offset	r^2
South Platte at 64th	14.12	7.86	111	0.898
Sand Creek Mouth	13.49	8.83	108	0.848
Clear Creek Mouth	13.01	8.61	108	0.850
Big Dry Mouth	12.69	10.01	106	0.892

Table 12. Basis for predicting temperatures for upstream and tributary flows in Segment 15. Values of a, b, and offset are related to the equation $T = a + bX$, where X equals sin (2π (day of year – offset)/365). The offset was adjusted to maximize r^2, which is shown in the last column of the table.

Monthly characteristic pH for effluent from Metro, South Adams, and Brighton was taken directly from a recent water quality assessment,[5] as shown in Table 13. Fort Lupton DMRs show only the minimum and maximum pH for each month. The midpoint [(maximum + minimum)/2] was calculated for each month, and the largest of annual midpoint values across years (July 1999 – August 2001) was selected from the set for each month (N=2 or 3). Selecting the largest midpoint value rather than the average

[5] South Platte River Segment 15 Water Quality Assessment. Analysis and Modelling in Support of Permitting for Discharges to the Middle and Lower Portions of Segment 15, South Platte River. William M. Lewis, Jr. and James F. Saunders, III. August 14, 2001.

Month	64^{th}	Metro combined	Sand Creek	Clear Creek	South Adams WWTP	Brighton WWTP	Big Dry Creek	Fort Lupton WWTP
Jan	7.69	6.90	8.06	8.23	7.00	7.55	8.13	7.82
Feb	7.73	6.90	8.06	8.37	7.00	7.58	8.16	7.65
Mar	7.56	6.90	7.95	8.17	7.00	7.60	7.94	7.55
Apr	7.39	6.90	7.83	7.97	7.00	7.61	7.71	7.64
May	7.46	7.00	7.90	7.93	7.00	7.65	7.75	7.45
Jun	7.54	7.10	7.96	7.90	7.00	7.78	7.78	7.45
Jul	7.61	7.10	8.03	7.86	7.00	7.78	7.82	7.65
Aug	7.76	7.10	7.83	7.76	7.00	7.80	7.74	7.70
Sep	7.52	7.10	7.69	7.90	7.00	7.75	7.60	7.50
Oct	7.49	7.00	7.95	8.00	7.00	7.70	8.01	7.55
Nov	7.62	6.80	8.06	7.95	7.00	7.75	8.07	7.65
Dec	7.66	6.90	8.06	8.09	7.00	7.51	8.10	7.75

Table 13. pH used to characterize source waters in the Segment 15 Water Quality Model.

makes the estimate slightly more conservative from the standpoint of unionized ammonia.

At 64th Avenue and the tributaries, pH was set independently of temperature because the record of concurrent pH and temperature measurements was inadequate. Because the diel data sets have been concentrated in the spring and late summer (April, August-October), values were not available for several months; these were estimated by linear interpolation.

Daily measurements of dissolved oxygen are available for South Adams and Brighton as well as Metro effluent; these were the basis for calculating medians (characteristic concentrations) for each month (Table 14). The data record for Fort Lupton consists only of monthly minima and maxima for January-August, 2001. The midpoint was determined for each of these eight months. For the remaining months, values were estimated by assuming a symmetrical distribution across months with a

Month	64th	Metro combined	Sand Creek	Clear Creek	South Adams WWTP*	Brighton WWTP*	Big Dry Creek	Fort Lupton WWTP
Jan	90%	5.7	90%	90%	4.5	4.5	80%	6.9
Feb	90%	6.0	90%	90%	4.5	4.5	80%	7.1
Mar	90%	6.3	90%	90%	4.5	4.5	80%	5.2
Apr	90%	6.1	90%	90%	5.0	5.0	80%	6.4
May	90%	5.9	90%	90%	5.0	5.0	80%	6.8
Jun	90%	5.5	90%	90%	5.0	5.0	80%	6.6
Jul	90%	5.1	90%	90%	5.0	5.0	80%	5.4
Aug	90%	6.0	90%	90%	4.5	4.5	80%	4.9
Sep	90%	6.2	90%	90%	4.5	4.5	80%	5.4
Oct	90%	6.2	90%	90%	4.5	4.5	80%	6.6
Nov	90%	5.5	90%	90%	4.5	4.5	80%	6.8
Dec	90%	5.7	90%	90%	4.5	4.5	80%	6.4

*Set by agreement among dischargers

Table 14. Dissolved oxygen concentrations (mg/L) or percent saturation used to characterize oxygen content of source waters in the Segment 15 Water Quality Model.

minimum in August (September was set equal to July, October was set equal to June, etc.). For the tributaries and the South Platte above 64th Avenue, dissolved oxygen concentrations were available from the diel studies but they cover only part of the year and the sample set is small (see comments above regarding the temperature data). There is also a strong connection between oxygen concentration and temperature that precludes lumping data across seasons. The problem was resolved by calculation of percent saturation on all dates and selection of a representative value (median, rounded to nearest 10%) that was applied to all months.

An ample data set exists for calculating monthly median concentrations of CBOD in the South Adams effluent (Table 15). The data set for Brighton is considerably

Month	64^{th}	Metro combined	Sand Creek	Clear Creek	South Adams WWTP*	Brighton WWTP*	Big Dry Creek	Fort Lupton WWTP
Jan	1.9	7.0	2.2	2.7	25.0	25.0	1.7	2.0
Feb	2.0	7.0	2.1	3.0	25.0	25.0	1.7	3.1
Mar	2.8	9.0	3.9	3.2	25.0	25.0	2.3	2.2
Apr	3.6	8.0	5.6	3.4	25.0	25.0	2.9	2.8
May	3.1	7.0	4.4	2.7	25.0	25.0	2.5	3.5
Jun	2.7	6.5	3.2	2.0	25.0	25.0	2.1	2.7
Jul	2.2	6.0	2.0	1.4	25.0	25.0	1.7	2.0
Aug	2.3	6.5	2.1	1.8	25.0	25.0	1.6	2.8
Sep	2.5	6.0	2.3	1.9	25.0	25.0	1.3	2.2
Oct	2.1	6.5	1.8	2.2	25.0	25.0	1.4	2.4
Nov	1.8	7.0	2.3	2.0	25.0	25.0	1.7	2.7
Dec	1.9	7.0	2.2	2.3	25.0	25.0	1.7	3.2

*Set by agreement among dischargers

Table 15. Five-day CBOD concentrations (mg/L) used to characterize water sources in the Segment 15 Water Quality Model.

smaller, but still adequate. The recent historical data record for Metro shows CBOD consistently below 10 mg/L; monthly medians are shown in Table 15. For the Fort Lupton effluent, monthly average and maxima are available for July 1999 through August 2001. The average of monthly average CBOD across years (N=2 or 3) is shown in Table 15. Concentrations are generally very low (2-3 mg/L), and much less than the limit of 30 mg/L for a 30-d average. For the South Platte at 64^{th} Avenue and tributaries, CBOD concentrations are available from the diel studies, although values for some months must be estimated by interpolation (see notes above regarding pH).

Concentrations of total ammonia at 64^{th} Avenue, Clear Creek, and Big Dry Creek were assigned on the basis of the diel studies in the same manner as for CBOD and dissolved oxygen, with interpolation as necessary to fill in data for months in which no diel studies were conducted (Table 16). Concentrations of ammonia in Sand Creek above the refineries were assumed to be zero, as explained in a recent assessment. [6,7] Concentration of total ammonia at the mouth of Sand Creek reflects mass balance calculations involving permit limits estimated recently for the refineries near the mouth of Sand Creek. For Fort Lupton, which characteristically shows very low ammonia concentrations (< 3.5) reflecting nitrification capability, total ammonia was set to 5.0 mg/L in all months. For South Adams and Brighton, concentrations were set to 25 mg/L as agreed to mutually by Metro and these two dischargers. Although Table 16 shows characteristic concentrations for Metro, these concentrations were adjusted during the phase of modelling that involves setting effluent limits, as explained in a subsequent section of this report.

Month	64th	Metro Combined*	Sand Creek	Clear Creek	South Adams WWTP**	Brighton WWTP**	Big Dry Creek	Fort Lupton WWTP
Jan	0.08	6.8	0.6	0.3	25	25	0.2	5.0
Feb	0.00	6.5	0.6	0.4	25	25	0.2	5.0
Mar	0.78	6.7	0.6	0.3	25	25	1.7	5.0
Apr	1.55	6.5	0.7	0.1	25	25	3.2	5.0
May	1.03	5.4	0.9	0.1	25	25	2.2	5.0
Jun	0.52	5.3	1.2	0.0	25	25	1.1	5.0
Jul	0.00	5.7	2.1	0.0	25	25	0.1	5.0
Aug	0.25	5.8	1.3	0.1	25	25	0.2	5.0
Sep	0.05	5.8	0.9	0.0	25	25	0.4	5.0
Oct	0.10	5.9	0.9	0.0	25	25	0.0	5.0
Nov	0.25	6.5	0.6	0.1	25	25	0.2	5.0
Dec	0.17	6.9	0.7	0.2	25	25	0.2	5.0

*Historical

**Set by agreement

Table 16. Total ammonia nitrogen concentrations (mg/L as N) used to characterize water sources in the Segment 15 Water Quality Model.

[6] South Platte River Segment 15 Water Quality Assessment. Analysis and Modelling in Support of Permitting on Lower Sand Creek and the Upper Portion of Segment 15, South Platte River. William M. Lewis, Jr. and James F. Saunders, III. May 24, 2001.

[7] South Platte River Segment 15 Water Quality Assessment, Analysis and Modelling in Support of Permitting for Discharges to the Middle and Lower Portions of Segment 15, South Platte River. William M. Lewis, Jr. and James F. Saunders, III. August 14, 2001.

Acute limits for these facilities were not used in modelling because coincidence of acute conditions for multiple dischargers is very unlikely. Ammonia concentrations were not assigned to the Metro effluent. These concentrations were left to be adjusted as necessary to produce overall compliance with stream standards for unionized ammonia and oxygen, as given in a subsequent section of this report.

Table 17 shows characteristic concentrations for nitrate nitrogen (usually reported as nitrite plus nitrate). Effluents are not listed because they were all treated as mutually adjustable as necessary to maintain 10 mg/L or less above points of compliance. Nitrate is treated in more detail in the addendum to this report dealing specifically with nitrate. Nitrate is carried along here, however, because of the necessity to calibrate the model for denitrification rates as part of the general model upgrade.

Month	64^{th}	Sand Creek	Clear Creek	Big Dry Creek
Jan	6.9	2.9	1.1	9.2
Feb	7.6	2.8	1.0	9.2
Mar	5.3	2.5	1.1	7.0
Apr	3.0	2.1	1.1	4.9
May	2.7	1.9	0.9	4.6
Jun	2.5	1.7	0.6	4.3
Jul	2.3	1.6	0.4	4.0
Aug	4.0	3.8	0.8	5.4
Sep	3.7	2.2	1.3	5.6
Oct	4.3	1.9	1.2	6.4
Nov	5.4	3.0	1.3	9.1
Dec	6.1	2.9	1.2	9.1

Table 17. Nitrate nitrogen concentrations (mg/L as N) used to characterize water sources in the Segment 15 Water Quality Model.

Adjustment of Rates for Temperature

Rates of all processes, including the physical process of reaeration and several biological processes, in the Segment 15 Water Quality Model respond to changes in temperature. Adjustment of rates for temperature is used in comparing rates at a standard temperature (20°C) and for applying rates to future conditions at a variety of temperatures. For a given process, observed median rates at 20°C are adjusted to reach-specific temperatures when the model is run for any set of future conditions. Rates at ambient temperature (K_T) are calculated from the rate at 20°C (K_{20}) with the following equation in which the coefficient (Θ) is different for each process (see Table 18):

$$K_T = K_{20} * \Theta^{(T-20)}$$

Process	Coefficient	Source
Community Respiration	1.0718	Assume $Q_{10} = 2$; $\Theta = 2^{(1/10)}$
Photosynthesis	1.0718	Assume $Q_{10} = 2$; $\Theta = 2^{(1/10)}$
Nitrification	1.080	Thomann and Mueller 1987[8]
Denitrification	1.045	Bowie et al. 1985[9]
CBOD removal	1.047	Thomann and Mueller 1987
Sediment Oxygen Demand	1.065	Thomann and Mueller 1987
Reaeration	1.024	Thomann and Mueller 1987

Table 18. Temperature adjustment parameters used in the Segment 15 Water Quality Model.

[8] Thomann, R.V. and J.A. Mueller. 1987. Principles of Surface Water Quality Modeling and Control. Harper & Row. New York.
[9] Bowie, G. L. et al. 1985. Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling. U.S. Environmental Protection Agency. Athens, GA.

Community metabolism analysis is based on observed rates of change in dissolved oxygen concentration over a 48-h period, as estimated from measurements made at intervals of about 4 hours. For any given interval of 4 hours, the reaeration rate is set to the average of temperature-adjusted values at the beginning and end of the interval. Then the rates of change in oxygen, corrected for reaeration, for all intervals are calculated and adjusted to a standard temperature of 20°C. The adjusted rates of change from this analysis are used to calculate community respiration and photosynthesis at a temperature of 20°C. The temperature adjustment coefficient is based on a Q_{10} of 2, which is a common way of characterizing the temperature response of many biological processes. The Q_{10} of 2 is converted to Θ so that all equations are of the same form. The conversion is accomplished with the following equation:

$$Q_T = Q_{10}^{(T-20)/10}$$
$$Q_T = 2^{0.1*(T-20)}$$
$$1.0718 = 2^{0.1}$$
$$Q_T = 1.0718^{(T-20)}$$

Temperature adjustments for the other processes are taken from a standard modeling reference (Thomann and Mueller 1987); each is a typical value drawn from a set of published values (e.g., the published values for the coefficient for CBOD removal range from 1.02 to 1.09).

Adjustments for temperature are slightly more complicated in the case of sediment oxygen demand (SOD), which is calculated as a residual (total observed demand minus all known demands). In the calibration step, the residual is computed as the difference between total community respiration and the sum of three of its four constituent processes (nitrification, CBOD, and algal respiration). The fourth process

(SOD) is the residual. Each process is estimated at ambient temperature and the resulting residual is converted to a rate at 20°C.

Reaeration Rates

Modelling of oxygen concentrations below the Metro District's discharge requires estimation of reaeration rates. Where reaeration rates are high, biological factors tending to suppress oxygen will have a smaller effect on observed oxygen concentrations than at other locations where reaeration rates are low. Factors promoting high reaeration rate include low mean depth, high velocity, large deviation from saturation concentration, and high temperature. For any given reach of stream that is reasonably uniform physically, empirical measurements can be used to estimate reaeration at ambient flow and temperature.

Field measurement of reaeration rates typically is conducted on a reach basis. Reaches are selected for reasonable physical uniformity, but even so may incorporate subsections of varying depth and velocity. Thus, some averaging of rates is inherent in empirical measurements. Ideally, measurements in free-flowing river reaches are separated from measurements that are made at structures. Entrainment of air at structures greatly enhances reaeration rate per unit distance. Thus, structures are treated separately.

Reaeration rates usually are measured by the addition of a tracer gas (typically propane). The tracer gas, which is of a type not normally present in the river in detectable quantities, escapes the water column at a rate proportional to the reaeration rate for oxygen. Field measurements involve the measurement of escape rate for the tracer gas based on travel time of water along a reach where measurements of gas concentrations are being taken. Travel time along the reach is estimated on the basis of a dye tracer.

The first estimates of reaeration rates on Segment 15 relevant to the modelling were made by the USGS in 1990. The EPA, using a slightly different method, made measurements in 1992. Beginning in 1996 and extending to the present, the Metro District has made all of the measurements that are appropriate for use in modelling.

Reaeration at drop structures is expressed as transfer efficiency at 20°C (abbreviated E20: Table 19). The current version of the Segment 15 Water Quality Model includes transfer efficiencies for 12 structures, eight of which are diversion dams. Of the other four structures, two were built for reaeration, one is a structure associated with the utilities crossing at 88th Avenue, and one is a structure under construction near 124th. Because the Metro District has used continuous propane injection in its field studies, repeated measurements of reaeration have been possible on the same study date. Thus, standard errors could be calculated, as reported in Table 18. For measurements prior to 1996, no standard error is available.

Several of the diversion structures have gates that are opened at the end of the irrigation season. When the gates are open, reaeration rates change substantially. Efficiency values for the non-irrigation season at structures that have open gates have been measured with propane only at the Fulton structure. Estimates at the Brantner and Brighton structures are based on change in dissolved oxygen (possible because reaeration rates at the structures can be quite high) under the open-gate condition; other estimates are based on the approximate ratio of reaeration for gates closed/open for other structures

(0.4). No measurements for the open-gate condition are available for Platteville and Evans structures. The reaeration characteristics for drop structures lacking an open-gate

Structure	E20 Closed Gate	s.e.	E20 with Open Gate		Data Source
Above 88th Avenue	0.252	0.019	NA		Metro
88th Avenue	0.092	0.023	NA		Metro***
Fulton	0.598	-	0.211		EPA; Open E20 by Metro (propane)
Near 104th Avenue	0.414	0.006	NA		Metro
Brantner	0.795	-	0.436		EPA; Open E20 by Metro (O_2)
Near 124th Avenue	*	-	NA		Construction Aug '01 - Jan '02
Brighton	0.615	0.006	0.333		Metro; Open E20 by Metro (O_2)
Lupton Bottom	0.164	0.019	NA		Metro
Platteville	0.740	0.020	0.417	**	Metro
Meadow Island 1	0.042	0.037	NA		Metro
Evans	0.598	-	0.305	**	Set equal to Fulton
Meadow Island 2	0.508	0.072	NA		Metro

* Determined using look-up table keyed to flows, provided by CDM.
**Special calculations described in text.
*** Recent modifications may have raised reaeration (undocumented).

Table 19. Oxygen transfer efficiencies of drop structures included in the Segment 15 Water Quality Model. Efficiencies are adjusted to 20°C (E20). The standard error of the mean (s.e.) is shown where available. A second E20 is listed for structures with gates that are opened after the irrigation season. NA= no open gate condition.

phase are assumed to be constant across all months.

Numerous measurements are available for river reaches not containing structures (Table 20). Table 20 also contains information on estimates made by means not involving direct field measurements. The reach between the Fulton and Brantner structures was subdivided recently by construction of a drop structure north of 104th Avenue. For modelling purposes, it is assumed that reaeration rates for reaches above and below the structure were not altered by addition of the structure. Also, adjustments were made to the reaeration rate measured by the EPA (11.18) for the reach below the Lupton Bottom ditch because the estimates were out of line with other observations. The basis for the adjustment was goodness of fit with observations. Additional studies are needed for this reach.

The drop structure efficiencies shown in Table 19 and the reaeration rates for reaches shown in Table 20 comprise the rates that were used in modelling the river between the 64th Avenue gage and Road 28. Month to month changes in reaeration rates for any structure or for any reach represented in the two tables are obtained by a temperature-based correction of the rate at 20°C. It is assumed for modelling purposes that changes in low-flow conditions from month to month are not sufficiently large to cause significant changes in reaeration rates.

Reach Start	Reach End	K2(20)	s.e.	Data Source
64th Avenue gage	Metro	11.45	-	USGS
Metro	78th Avenue	11.25	-	EPA
78th Avenue	Above drop	19.26	1.41	Metro
Below drop	Above 88th Avenue	6.81	0.73	Metro
Below 88th Avenue	McKay	6.80	0.73	Metro
McKay	Fulton Pool	7.17	4.08	Metro
Fulton Pool	Above Fulton	2.15	1.15	Metro
Below Fulton	Above 104th drop	3.47	2.17	Metro; with adjustments for pool
Below 104th drop	Brantner Pool	3.47	2.17	Set equal to previous reach
Brantner Pool	Above Brantner	0.50	-	Estimated
Below Brantner	124th Avenue	11.92	0.41	Metro
124th Avenue	Above Brighton	8.47	0.21	Metro
Below Brighton	Above Lupton Bottom	10.15	0.25	Metro
Below Lupton Bottom	Above Platteville	7.10	-	EPA
Below Platteville	Above Meadow Island 1	9.65	-	Average of adjacent reaches
Below Meadow Island 1	Above Evans	12.19	1.24	Metro
Below Evans	Above Meadow Island 2	12.50	0.66	C.U.
Below Meadow Island 2	Road 28	12.50	-	Set equal to previous reach

Table 20. Reaeration rates of stream reaches included in the Segment 15 Water Quality Model. All rates are adjusted to 20°C [K2(20), d^{-1}]. Standard error is shown where available.

Prediction of Minimum Dissolved Oxygen Concentrations

Standards for dissolved oxygen in Segment 15 include not only 30-day averages values but also minima. Although the chronic (30-d) averages characteristically have been the source of the most restrictive requirements for dischargers, instantaneous minima must be considered as well.

Approaches that were investigated for Segment 15 modelling, include empirical regression analysis, a theoretical approach based on Livingstone's work[10], and simply turning off photosynthesis. The empirical approach makes a prediction of the minimum based on the predicted mean DO and the rate of primary production; this approach was used in the previous calibration. Unfortunately, the regression line explains too small a proportion of the variance for the present calibration effort. Livingstone's approach has strong appeal because of its theoretical underpinnings, but is difficult to implement with reaeration rates that are low (pool) or high (structures). In addition, the method for setting total oxygen demand depends on knowing all components of demand, and thus is little different from the accumulation of deficit terms used in the model.

The third approach, which involves use of the model to eliminate photosynthesis, was the basis for estimation of minimum dissolved oxygen in the earliest versions of the Segment 15 Water Quality Model. It was abandoned because an alternate method gave better results during the last recalibration, but with the current data elimination of photosynthesis is the best approach. The model conditions are set to acute and photosynthesis rates are set to zero. The cumulative effect of the demand terms then produces an estimate of DO based on demand terms only, which correspond to minimum DO. This method, which produces best results with current data, is incorporated into current modelling.

Metabolic Changes in the South Platte River

During the mid-1990s, it became evident from examination of raw data on dissolved oxygen concentrations from diel studies that the South Platte River had undergone a metabolic change leading to lower community respiration rates. During the last recalibration, however, it was not clear whether these lower rates would be sustained. Therefore, some of the earlier, higher rates were included in the recalibration.

For the present recalibration, it is possible to reexamine the issue of metabolic changes in the South Platte with the benefit of approximately five years of monitoring since the last calibration. Based on this examination, a decision can be made as to the relevant rates to be used in the current version of the model.

The index that was used in examining metabolic status of the South Platte River is the nighttime saturation deficit, as shown by 24-hour monitoring, which is determined from the ratio of community respiration rate to the reaeration rate. For any given reaeration rate, the degree to which oxygen concentration is suppressed below saturation at night will depend on the respiration rate, including both water column and sediment demand. This estimate cannot be made during the day because of complications related to photosynthesis. The reaeration rate (K, d^{-1}) for any given set of site-specific conditions

[10] Livingstone, D. M. 1991. The diel oxygen cycle in three subalpine Swiss streams. *Arch. Hydrobiol.*

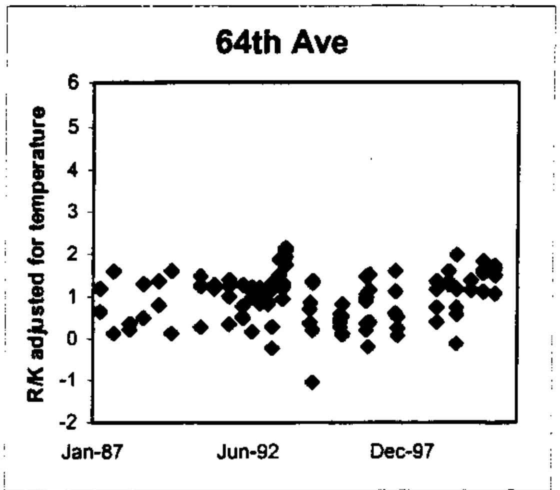
must also be taken into account, however, because the saturation deficit for a given respiration rate (R, $mgO_2/L/day$) will decrease with increasing reaeration rate. The ratio of respiration to reaeration (R/K, mgO_2/L; estimated deficit) therefore can be used as a general index of change in metabolic status with regard to respiration.

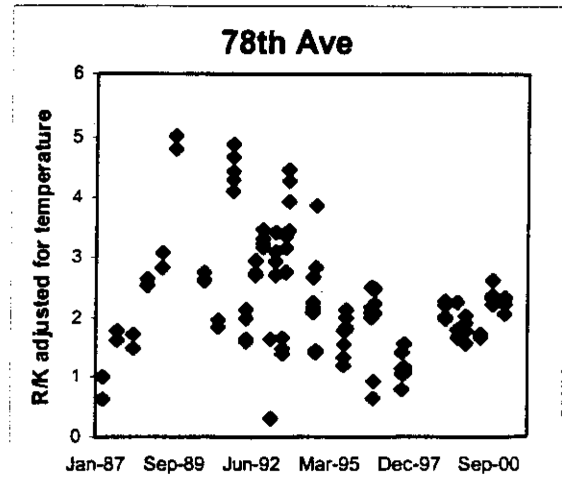
Figure 9 shows the R/K ratios for locations of diel studies since 1987. As indicated by the figure, the 64th Avenue station, above the Metro outfall, shows no indication of systematic metabolic change. In contrast, the 78th Avenue station, which is below Metro, shows a large rise in respiration beginning in 1988 and leading to a peak in respiration rates about 1990 and a decline to the 1987 level by 1994-1995. Prior to 1988, the rates were lower and much steadier than between 1988 and 1994. The same trend appears at 88th Avenue and downstream, but the magnitude of the change decreases in the downstream direction. At Road 8 and below, there is no indication of change.

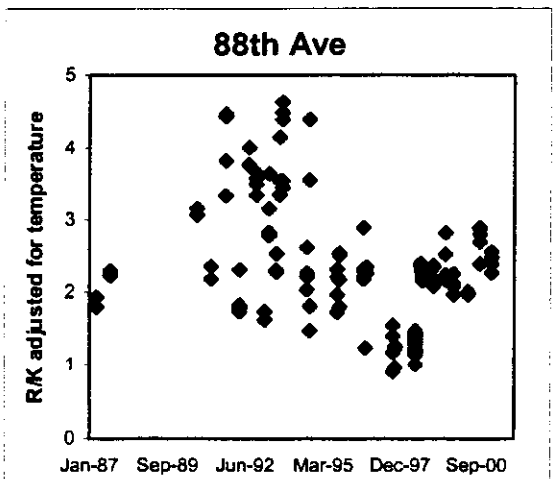
The mechanism causing the metabolic change in the South Platte River below Metro's outfall is a matter of speculation. The onset of greatly increased respiration coincided, however, with the onset of dechlorination (1988). Thus, it appears likely that respiratory rates were being depressed in the South Platte River by the discharge of chlorine. The result was an accumulation of labile organic matter in the sediments or toward the edges of the river channel. When dechlorination was introduced, the stored organic matter was more readily attacked by bacteria, and was degraded over a period of several years. Subsequently, the respiration rate returned to equilibrium.

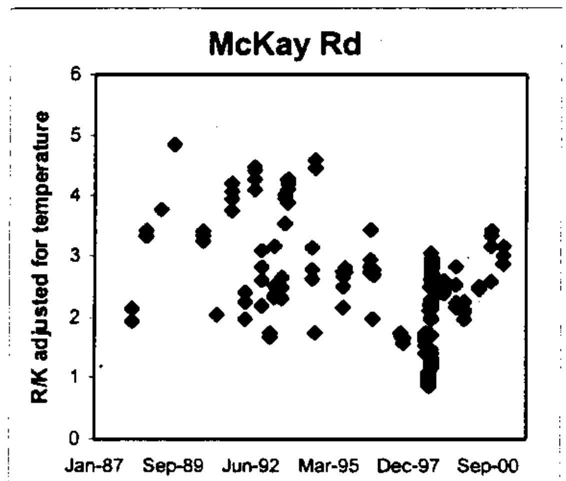
Given the observations represented in Figure 9, it is clear that current modelling should be based on respiration rates beginning no earlier than 1995.

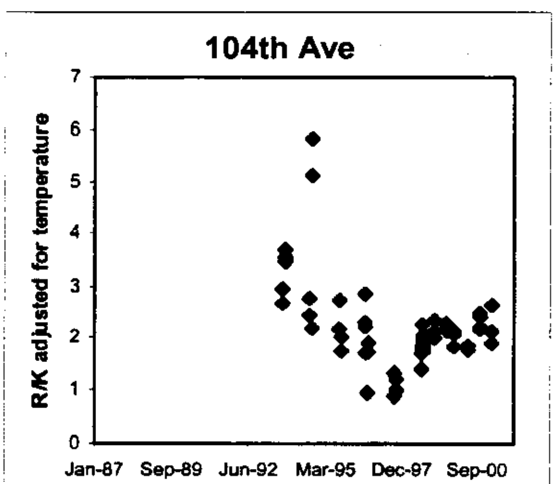
120: 457-479.

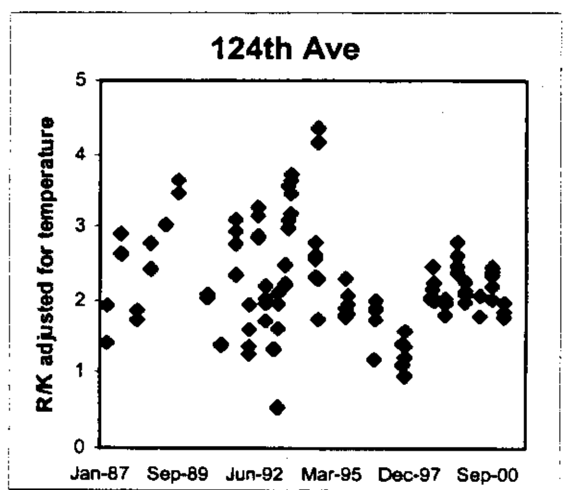

64th Ave
R/K adjusted for temperature
6
5
4
3
2
1
0
-1
-2
Jan-87
Jun-92
Dec-97


78th Ave
R/K adjusted for temperature
6
5
4
3
2
1
0
Jan-87
Sep-89
Jun-92
Mar-95
Dec-97
Sep-00


88th Ave
R/K adjusted for temperature
5
4
3
2
1
0
Jan-87
Sep-89
Jun-92
Mar-95
Dec-97
Sep-00


McKay Rd
R/K adjusted for temperature
6
5
4
3
2
1
0
Jan-87
Sep-89
Jun-92
Mar-95
Dec-97
Sep-00


104th Ave
R/K adjusted for temperature
7
6
5
4
3
2
1
0
Jan-87
Sep-89
Jun-92
Mar-95
Dec-97
Sep-00


124th Ave
R/K adjusted for temperature
5
4
3
2
1
0
Jan-87
Sep-89
Jun-92
Mar-95
Dec-97
Sep-00

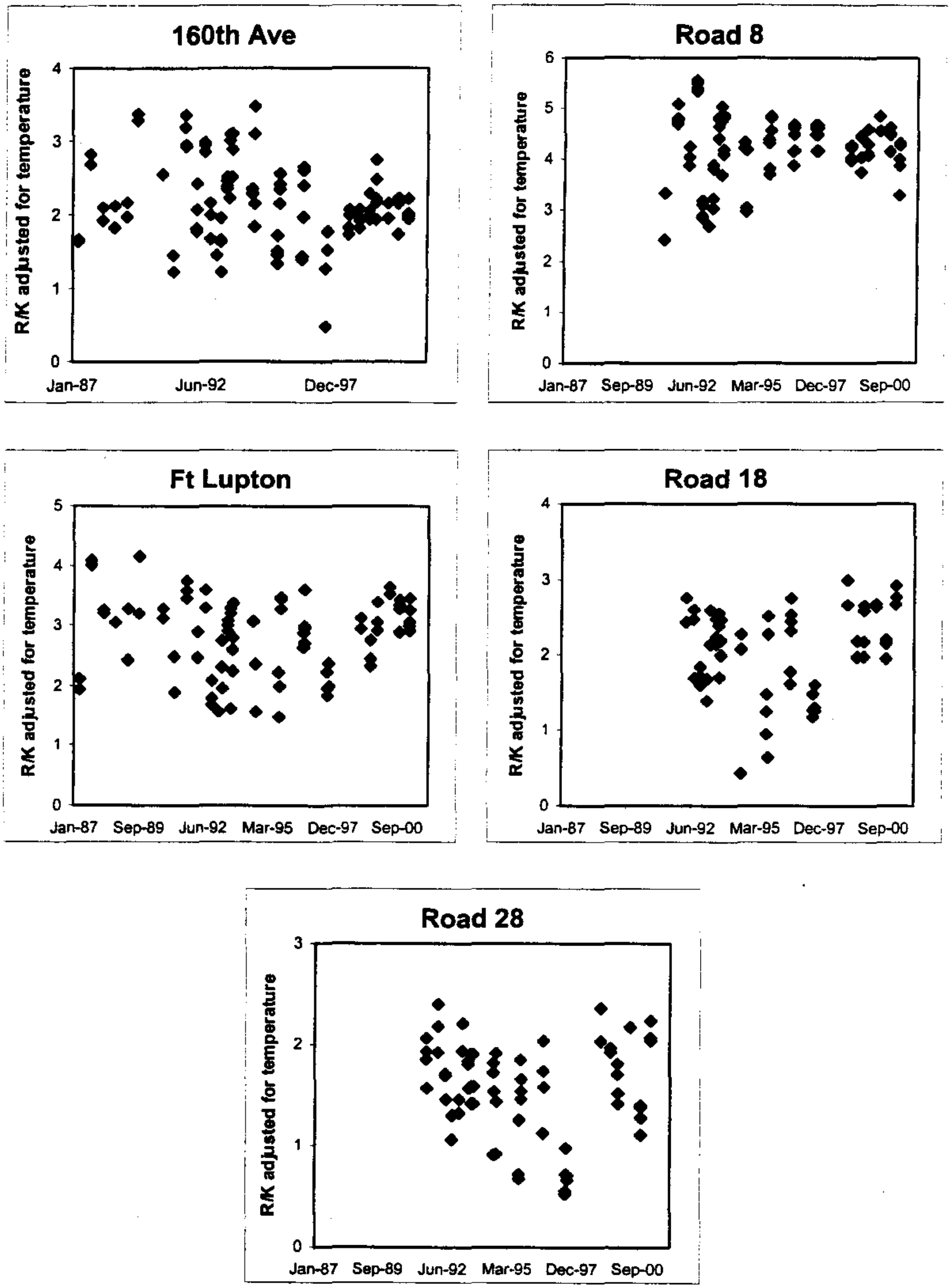


Figure 9. Ratios of community oxygen demand to reaeration (see text).

Use of CAM in Support of Ammonia Modelling

Consistency with permitting practice requires that the Colorado Ammonia Model (CAM) be used in support of ammonia modelling. CAM is software that computes maximum allowable concentrations of total ammonia in an effluent discharge or in multiple effluent discharges consistent with Colorado's ammonia standards. The software takes into account 24-hour variations in pH and temperature, rebound of pH and temperature below points of discharge, mixing of flows having different pH and temperature, and temporal variation in pH and temperature. The detailed treatment of pH and temperature by CAM is important in that both of these variables affect the proportion of total ammonia that is unionized.

CAM incorporates default settings for diel variation and for rebound rates. It is advisable, however, for site-specific numbers to be inserted in place of these default values wherever possible. For the modelling described here, examination of site-specific values for use in CAM was possible because of the monitoring programs of the Metro District.

The first step toward ammonia modelling was to make estimates of 24-hour amplitude in variation of temperature and pH. The 24-hour values are available from diel studies at ten locations (78th, 88th, McKay, 104th, 124th, 160th, Road 8, Fort Lupton, Road 18, Road 28). Diel studies are not available equally for all months, however. Diel studies were used to characterize a month or a group of months for which three or more study dates were available, as was the case for August, September, October, February-March, and April-May. Characteristics of other months were obtained by interpolation. A comparison of data on amplitudes across the years since 1987 showed no evidence of systematic change in amplitudes across years. Consequently, all years were used in estimating amplitudes.

Table 21 summarizes the data for temperature ranges (amplitude = 50% of range). Ranges tend to be higher downstream than upstream, as expected. For pH, inspection of the data show no pattern across years for 160th and stations downstream of 160th. Stations at and above 124th, however, show a trend in pH. This trend is probably related to the changes in community respiration that occurred since monitoring began. Inspection of the ranges as a function of time, however, shows no trend in ranges at any given station. Therefore, for the purpose of obtaining amplitudes through the estimation of ranges, all years can be used.

There is a discontinuity in pH values between October 1996 and September 1997; the pH values for a given time of year increase a few tenths across all stations over this interval. This discontinuity suggests a methodological problem. Because the main purpose of the analysis is to estimate amplitudes, however, shift in the mean is not important to this part of the analysis.

The year was divided into three clusters of months for purposes of estimating amplitude in pH: late summer (August-October), winter (January-March), and spring (April-May). Because the values for these clusters showed no systematic difference, however, annual medians were used for each location (Table 21).

The second step in the analysis was to obtain 24-hour average values corresponding to the grab sample measurements at five of the six biweekly sampling sites. A sampling site above the Clear Creek confluence was excluded because field data suggest that the samples from this site do not show chemistry representative of the main part of the channel. Data from the five sites were screened for possible errors.

Locations	Months				
	August	September	October	February-March	April-May
Temperature					
78^{th} Avenue	4.18	3.68	4.38	5.77	4.63
88^{th} Avenue	4.53	4.52	5.71	4.97	5.26
McKay Road	4.43	4.54	5.23	5.37	5.13
104^{th} Avenue	4.93	5.58	5.30	5.40	6.20
124^{th} Avenue	4.10	4.21	4.53	4.67	4.97
160^{th} Avenue	5.37	5.00	5.27	4.40	5.94
Road 8	5.57	5.12	5.61	5.23	6.15
Fort Lupton	6.10	5.14	5.48	4.83	6.20
Road 18	7.10	5.14	6.08	4.77	6.13
Road 28	8.13	5.22	6.90	4.80	7.47

pH	All Months
78^{th} Avenue	0.34
88^{th} Avenue	0.40
McKay Road	0.32
104^{th} Avenue	0.36
124^{th} Avenue	0.36
160^{th} Avenue	0.42
Road 8	0.44
Fort Lupton	0.28
Road 18	0.30
Road 28	0.33

Table 21. Ranges in temperature and pH as determined from diel studies.

Expectations for a large stream that is well-buffered, as is the South Platte, are that 24-hour pH values will be very similar across stations on the same date, and similar for proximate dates at the same station. In addition, the frequency distribution of 24-hour pH values at a given site will show a small degree of dispersion.

A complete list of pH values recorded on all dates after 1995 is shown in Table 22. Blanks indicate no data available.

Date	78th	88th	McKay	124th	160th
11-Jan-96	7.3	7.3	7.3	7.1	6.5
24-Jan-96	7.3	7.5	7.5	7.4	6.9
7-Feb-96	6.7	6.9	7.0	7.0	7.1
21-Feb-96		**6.6**	6.9	6.8	6.7
7-Mar-96	7.0	7.2	7.3	7.1	7.0
20-Mar-96	6.7	7.2	7.2	7.5	7.7
3-Apr-96	7.2	7.6	7.7	7.5	7.6
18-Apr-96	7.0	7.2	7.3	7.4	7.5
7-May-96	7.3	7.5	7.7	7.5	7.6
22-May-96	6.5	7.0	6.7	6.7	7.4
7-Jun-96	**6.1**	**6.6**		6.7	6.5
18-Jun-96	6.8		7.0	6.9	**6.3**
9-Jul-96	7.0	7.2	7.3	7.3	7.3
24-Jul-96	7.2	7.1	7.0	7.2	7.2
8-Aug-96	7.1	7.4	7.4	7.3	7.4
21-Aug-96	7.1	7.2	7.2	7.3	7.4
11-Sep-96	6.9	7.1	7.0	7.0	7.1
26-Sep-96	6.7	6.8	7.3	7.4	7.4
8-Oct-96	7.0	7.1	7.1	7.3	7.2
24-Oct-96	6.8	7.0	7.4	7.2	7.0
8-Nov-96	7.1	7.1	6.8	6.8	7.0
20-Nov-96	7.4	7.5	7.5	7.5	7.4
3-Dec-96	7.5	7.5	7.4	7.4	7.3
16-Dec-96	7.0	7.2	6.8	7.3	6.9
8-Jan-97	7.0	7.0	7.1	7.4	7.3
21-Jan-97	6.8	7.0	7.0	7.1	7.0
6-Feb-97	7.6	7.6	7.6	7.5	7.1
19-Feb-97	6.9	6.9	7.0	6.9	6.7
4-Mar-97	7.0	7.1	7.1	7.1	7.0
19-Mar-97	6.8	7.4	7.1	7.2	7.2
3-Apr-97	7.4	7.7	7.7	7.6	7.3
16-Apr-97	6.8	7.0	7.1	7.3	7.4
7-May-97	6.7		6.8	7.1	7.4
22-May-97	7.3	7.2	7.2	7.0	7.0
10-Jun-97	7.2	7.2	7.2	7.2	7.2
25-Jun-97	7.3	7.3	7.5	7.4	7.3
9-Jul-97	7.5	7.6	7.7	7.7	7.6
22-Jul-97	**7.8**	***7.8*** *	***8.0*** *	7.5	7.3
6-Aug-97		7.7	7.6	7.7	7.8
21-Aug-97	7.4	7.4	7.4	7.5	7.5
10-Sep-97	7.6	7.6	7.6	7.6	7.7
24-Sep-97	6.7	6.9	6.8	6.9	6.9
8-Oct-97	7.6	7.6			
23-Oct-97	7.4	7.6	7.6	7.7	7.5
4-Nov-97	7.3	7.4	7.5	7.5	7.5
19-Nov-97	7.3	7.3	7.3	7.3	7.1
4-Dec-97	7.0	7.1	7.2	7.0	6.6
16-Dec-97	7.4	7.5	7.5	7.6	7.6
7-Jan-98	7.6	7.5	7.6	7.6	7.4
22-Jan-98	7.1	7.2	7.4	7.5	7.4
3-Feb-98	7.3	7.3	7.4	7.3	7.4
19-Feb-98	6.9	7.2	7.1	7.2	7.1
5-Mar-98	7.2	7.6	7.4	7.5	7.6
20-Mar-98		7.4	7.7	7.4	7.4
7-Apr-98	7.3	7.3	7.3	7.3	7.2
23-Apr-98	7.3	7.3	7.4	7.3	7.3

5-May-98	7.4	7.4	7.4	7.4	7.1	
19-May-98	7.2	7.3	7.3	7.5	7.5	
10-Jun-98	7.2	7.2	7.2	7.2	7.0	
23-Jun-98	7.2	7.2	7.3	7.4	7.3	
15-Jul-98	7.1	7.5	7.2	7.3	7.3	
28-Jul-98	7.4	7.4	7.5	7.5	7.5	
13-Aug-98	7.4	7.4	7.4	7.5	7.5	
26-Aug-98	7.5	7.6	7.6	7.7	7.7	
16-Sep-98	7.6	7.6	7.7	**8.0**	***8.1***	*
7-Oct-98	7.1	7.3	7.4	7.5	7.6	
21-Oct-98	7.1	7.3	7.4	7.4	7.4	
4-Nov-98	7.0	7.2	7.2	7.3	7.4	
18-Nov-98	7.1	7.3	7.4	7.3	7.3	
2-Dec-98	7.1	7.2		7.2		
16-Dec-98	7.3	7.3		7.4		
6-Jan-99	7.0	7.0	6.7	7.2		
20-Jan-99	7.1	7.0	7.6	6.8		
3-Feb-99	6.7	6.8	7.7	7.0	7.4	
17-Feb-99	7.0	7.2	7.3	7.0	7.3	
3-Mar-99	7.0	7.2	7.6	7.2	7.2	
17-Mar-99	7.1	7.2	7.4	7.2	7.5	
7-Apr-99	7.1	7.3	7.3	7.5	7.2	
21-Apr-99	7.2	7.3	7.2	7.3	7.5	
5-May-99	7.1	7.1	7.4	7.1	7.2	
19-May-99	7.3	7.2	7.5	7.2	7.2	
2-Jun-99	7.4	7.5	8.0	7.4	7.0	
16-Jun-99	7.5	7.6	7.5	7.4	7.0	
7-Jul-99	7.4	7.3	7.5	7.4	7.0	
21-Jul-99	7.3	7.4	7.4	7.4	7.1	
4-Aug-99	7.6	7.6		7.4	7.2	
18-Aug-99	7.4	7.4	6.9	7.4	7.1	
1-Sep-99	7.2	7.3	6.7	7.0	7.1	
15-Sep-99	7.4	7.3	6.7	7.4	7.4	
6-Oct-99	7.5	7.6	7.1	7.4	7.2	
20-Oct-99	7.4	7.6	7.1	7.6	7.3	
3-Nov-99	6.9	7.4	7.6	7.2	7.7	
17-Nov-99	7.4	7.5	7.3	7.6	7.7	
1-Dec-99	7.0	7.3	7.4	7.5	7.8	
15-Dec-99	7.1	7.3	7.4	7.4	7.9	
5-Jan-00	7.1	7.2	7.5	7.2	7.6	
19-Jan-00	7.0	7.0	7.6	7.3	7.6	
2-Feb-00	7.0	7.1	7.3	**5.7**	7.4	
16-Feb-00	6.9	7.0	7.2	7.2	7.4	
1-Mar-00	7.1	7.2		7.2	7.4	
15-Mar-00	7.3	7.4	7.4	7.5	7.4	
5-Apr-00	7.0	6.9	7.3	7.0		
19-Apr-00	7.1	7.2	7.8	7.3		
3-May-00	6.8	6.9	7.3	7.2		
17-May-00	7.4	7.3		7.6		
7-Jun-00	7.1	7.1	7.5	7.2		
21-Jun-00	6.9	7.0		7.1		
5-Jul-00	6.9	7.0	7.7	7.1	7.5	
19-Jul-00	7.0	7.2		7.1		
2-Aug-00	6.8	7.0	7.7	6.9	7.8	
16-Aug-00	6.9	7,2		7.2		
6-Sep-00	6.8	6.9	7.4	7.0	7.5	
20-Sep-00	6.9	**6.1**		**6.2**		

4-Oct-00	**8.1**	7.3	7.2	7.4	7.4
18-Oct-00	**5.9**	**5.9**		**6.5**	
1-Nov-00	7.1	7.4	7.0	7.4	7.5
15-Nov-00	6.9	**5.8**		6.9	
6-Dec-00	**6.5**	**6.4**	7.1	7.2	7.6
27-Dec-00	7.1	7.3		7.4	

*Note italics.

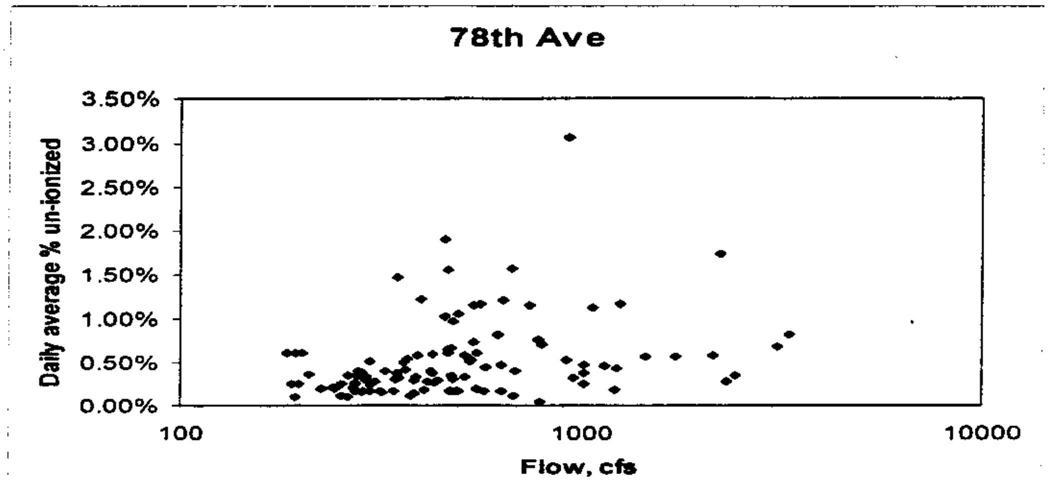
Table 22. A listing of pH data from biweekly monitoring sites. Outliers (as identified from box and whisker analysis[11]) are shown in bold. Additional data of concern are shown in italics (see text).

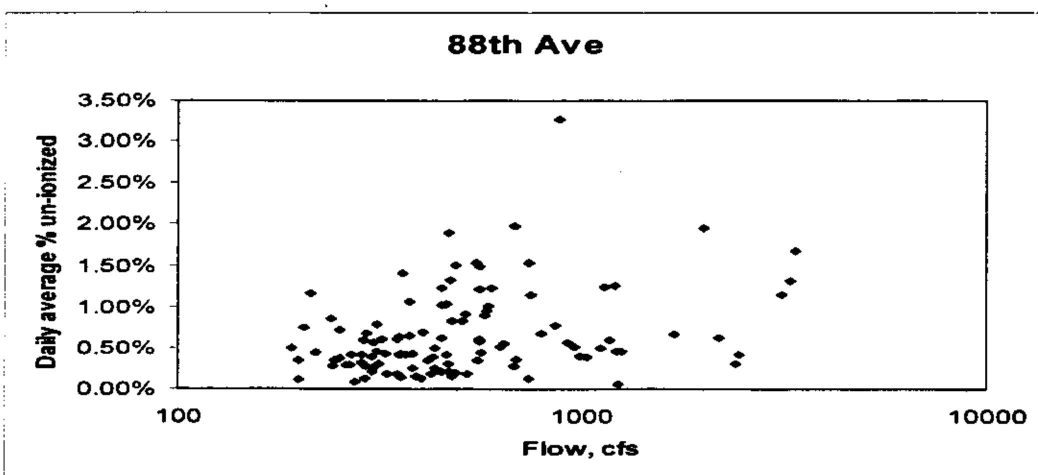
All outliers were eliminated from subsequent analyses. Other pH values (shown in italics) were excluded from the data set because they were part of a cluster including outliers, indicating methodological problems on a particular date. Exclusion of outliers has negligible effect on setpoints for this analysis (see setpoint estimation procedure below).

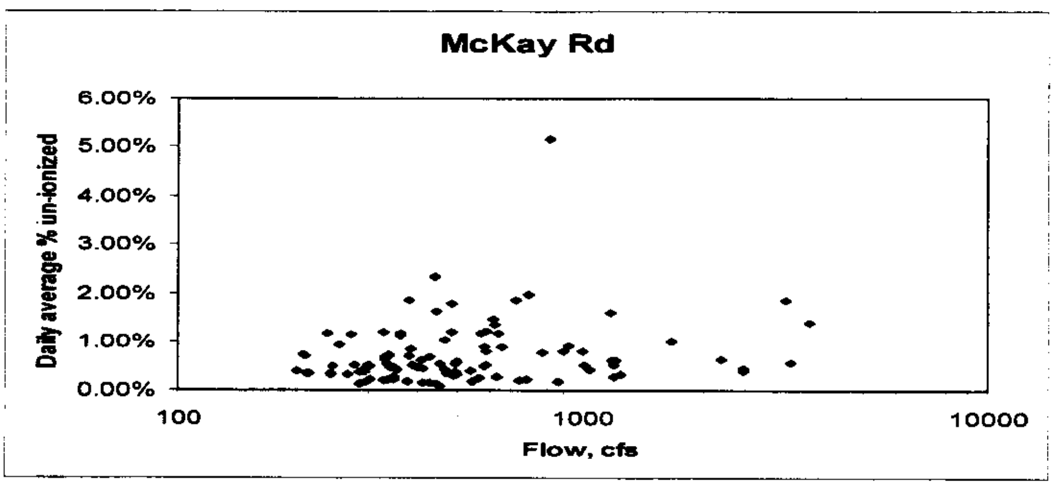
Each measurement in the screened data sets was converted to a 24-hour equivalent by use of CAM software and the amplitudes shown in Table 21. Setpoint conditions were then derived from the data at each station, but not by use of CAM software.

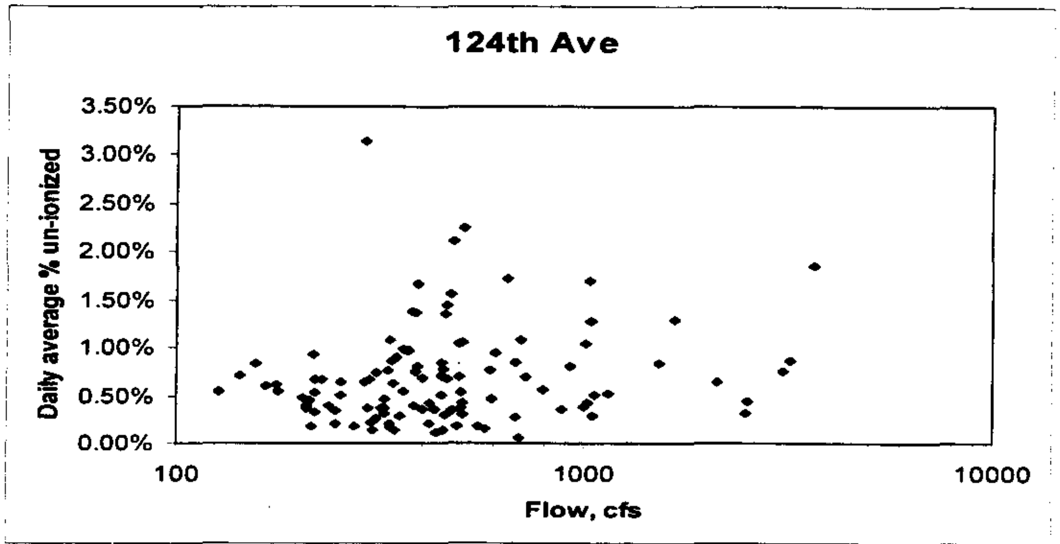
Statistical analysis shows that there is no relationship between regulatory low flows and percent unionized ammonia in Segment 15 of the South Platte River (Figure 10). Whereas such a relationship would be expected in many Colorado streams, intensive

[11]As given by Statistix for Windows, Analytical Software, 1998. Whiskers extend 1.5x the height of the box; values beyond whiskers are excluded.


78th Ave
Daily average % un-ionized
3.50%
3.00%
2.50%
2.00%
1.50%
1.00%
0.50%
0.00%
100
1000
10000
Flow, cfs


88th Ave
Daily average % un-ionized
3.50%
3.00%
2.50%
2.00%
1.50%
1.00%
0.50%
0.00%
100
1000
10000
Flow, cfs


McKay Rd
Daily average % un-ionized
6.00%
5.00%
4.00%
3.00%
2.00%
1.00%
0.00%
100
1000
10000
Flow, cfs



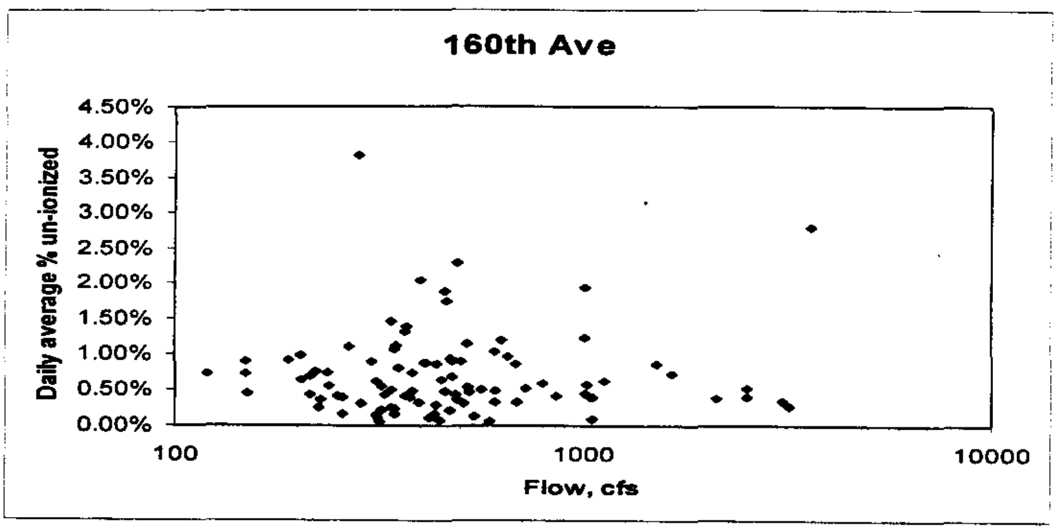


Figure 10. Plot of flow versus percent unionized ammonia along the South Platte River Segment 15.

water management has disrupted the relationship in Segment 15. CAM analysis assumes an association between extreme percent unionized ammonia and extreme low flows. Because such an assumption is demonstrably false for the South Platte River, an alternate approach is justified. The median percent unionized ammonia is matched with low flows for each of the locations where setpoints are established through monitoring. The median temperature for each of these locations is also determined and is designated as the setpoint temperature (setpoint value corresponds to low flow). The pH necessary to generate the observed median percent unionized ammonia from the observed median temperature is designated the setpoint pH in each case. Because medians are used, acute and chronic setpoints are identical. Results are shown in Tables 23-24.

Setpoint conditions at McKay Road, are out of line with expectations based on values at adjacent stations sometimes (especially for pH). Differences in labs or differences in the frequency of sampling (South Adams has sampled the McKay Road site since the inception of the SP CURE program) probably have contributed bias that cannot be controlled for except through elimination of the data. The model uses the average of values at 88th and 124th rather than the data for McKay shown in the tables.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
78th	10.28	11.84	13.33	14.40	15.95	14.92	21.91	21.76	20.76	17.78	14.48	12.66
88th	8.81	10.90	12.08	13.86	15.74	16.18	21.97	21.40	20.98	17.51	13.97	10.50
McKay	8.70	10.92	10.60	13.48	15.88	15.38	21.20	21.01	20.48	15.63	13.11	9.25
124th	9.10	9.79	10.10	12.94	16.16	15.93	21.54	20.76	19.82	15.33	12.79	9.14
160th	7.72	9.77	9.38	12.58	16.33	16.82	21.92	20.99	20.42	14.42	12.38	8.33
Road 28*	7.72	9.77	9.38	12.58	16.33	16.82	21.92	20.99	20.42	14.42	12.38	8.33

*No field data; set equal to 160th.

Table 23. Setpoint conditions for temperature at biweekly monitoring sites in Segment 15.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
78th	6.98	6.87	7.01	7.14	7.23	7.24	7.30	7.40	6.96	7.18	7.11	7.04
88th	7.05	6.99	7.25	7.25	7.25	7.24	7.40	7.45	7.23	7.34	7.37	7.26
McKay	7.34	7.15	7.35	7.31	7.32	7.41	7.50	7.45	7.11	7.27	7.25	7.26
124th	7.24	7.00	7.32	7.40	7.30	7.33	7.43	7.49	7.16	7.48	7.41	7.33
160th	7.30	7.25	7.38	7.47	7.38	7.06	7.37	7.51	7.34	7.33	7.46	7.46
Road 28*	7.30	7.25	7.38	7.47	7.38	7.06	7.37	7.51	7.34	7.33	7.46	7.46

*No field data; set equal to 160th.

Table 24. Setpoint conditions for pH at biweekly monitoring sites in Segment 15.

Rebound rates, the final aspect of the ammonia analysis, are treated differently for the Segment 15 model than is standard for CAM because the abundance of data opens a better option. In a typical CAM analysis, setpoint is defined on the basis of measurements taken at one location, and it is rare to have information downstream defining a site-specific rebound rate. In Segment 15, the biweekly monitoring program makes it possible to define setpoint at several locations and to estimate rebound rates directly based on differences between locations. In the model, pH and temperature change linearly in proportion to distance between each of the setpoint locations listed in Tables 23 and 24. This approach is most likely to mimic correctly the downstream changes in pH and temperature.

Channel Dimensions and Travel Time in the Segment 15 Water Quality Model

Benchmark conditions consisting of width and mean depth at a known flow are available for many transects along Segment 15. Most of the data south of Fort Lupton were obtained in surveys conducted by HabiTech prior to 1995. These data were supplemented with additional measurements made by the Metro District, CDM and its sub-contractors, and CU.

Several biological processes (primary production, community respiration, nitrification, SOD) are estimated initially as rate per unit volume (L^{-1}) and must be converted to an area (m^{-2}) as a step toward prediction of longitudinal changes in concentration of oxygen or ammonia. Conversion depends on the mean cross-channel depth of water, which changes with discharge. The mean depth at a modeled flow (D_m) is calculated from the benchmark mean depth (D_b, mean depth on the date of survey), the ratio of modeled flow (Q_m) to benchmark flow (Q_b, flow on the date of survey), and the exponent of the channel geometry equation (f):

$$D_m = D_b * (Q_m/Q_b)^f$$

The following is a similar equation for width:

$$W_m = W_b * (Q_m/Q_b)^b$$

Values for f and b, as obtained from field data at several stations, are shown in Table 25.

Reaches	Depth (f)	Width (b)	Source
64th Avenue – RM310.47	0.314	0.162	Henderson gage
RM310.47 – RM308.61	0.445	0.058	Near 78th
Fulton Pool	0.426	0.050	Estimated
RM308.61 – 160th Avenue	0.314	0.162	Henderson gage
160th Avenue – Evans Ditch	0.376	0.443	Fort Lupton gage
Evans Ditch – Road 28	0.455	0.147	Tailgate Ranch (Road 24)

Table 25. Exponents for channel geometry equations defining the relationships between width and discharge as well as depth and discharge at selected locations along the South Platte between 64th Avenue and Rd 28. RM = river miles as defined in the model (Table 1).

Stream velocity was calculated as discharge divided by cross-sectional area (area = width x mean depth). Stream width for any given flow was determined with the equation outlined above. Downstream of 160th Avenue, a factor of 0.757 was applied to velocity calculations to bring estimates into line with observations.

At diversion structures, width (W) was assumed constant and depth was assumed to respond to discharge as predicted with the following equation (standard equation for depth-flow relations at weirs):

$$D_m = (Q_m/W)^{2/3}/32.2^{1/3}$$

Community Metabolism in the Segment 15 Water Quality Model

Community metabolism is a system-level measure of biological processes defined by mass flux of dissolved oxygen. Diel changes in the concentration of dissolved oxygen reflect the cumulative effects of primary production and community oxygen demand. Community oxygen demand includes demand for oxygen from all biological sources, including respiration and nitrification (which is not a respiratory process). Estimates of community metabolism are central to the modelling of oxygen.

Oxygen data from the diel studies are the basis for calculating community metabolism by the single-station method of Odum (1956). More sophisticated computational methods exist, but they require more frequent measurements of dissolved oxygen than are available from the diel studies. For present purposes, observed rates of change in the concentration of dissolved oxygen were calculated over each time interval for each diel study, and these were adjusted for exchange with the atmosphere based on independently measured reaeration rates in each reach (see section on reaeration). Rates of change in oxygen concentration at night, when adjusted for reaeration, were the basis for calculating community oxygen demand; increases in oxygen concentration during daylight hours, when adjusted for reaeration, were the basis for calculating rates of photosynthesis.

Flow was used to calculate average depth for the reaches to which a particular set of rates would be applied (see section on discharge, width, and depth). Volumetric rates then were multiplied by mean depth to yield areal rates ($gO_2/m^2/d$). Rates of photosynthesis and oxygen demand derived in this way were adjusted to 20°C with the assumption that the Q_{10} of these metabolic processes is close to 2.0. Because no seasonal trends were evident in the temperature-adjusted rates, median temperature-adjusted rates were used across all months for a given site. The model adjusts the median rates for expected temperatures in a given month.

Estimates of photosynthesis were expressed as a ratio to solar radiation (W/m^2). Thus, predicted rates could be adjusted for the amount of sunlight expected in a particular month. Sunlight data were obtained from NOAA in Boulder.

Oxygen demand is partitioned into four processes. Oxygen demand associated with CBOD removal (microbial respiration, a biological process, plus settling, a physical process) was estimated from observed loss rates of CBOD. Nitrification, a biological ammonia-conversion process, was estimated from the observed loss rates of ammonia. Oxygen demand attributable to algal respiration is assumed to be a fixed fraction (20%) of algal photosynthesis. The difference between total community oxygen demand and the sum of the three processes just described is assumed to be sediment oxygen demand (SOD), a microbial respiratory process.

Biogeochemical processes involving nitrogen affect the oxygen balance and therefore must be accounted for in the model. As already mentioned, nitrification, which involves the conversion of ammonium to nitrate by microbes, is an oxygen-consuming process. The process of nitrification consumes dissolved oxygen a two-step process that converts ammonia to nitrite, and nitrite to nitrate. For each gram of ammonia converted to nitrate, 4.57 grams of oxygen are consumed. It would be unrealistic, however, to base nitrogenous oxygen demand (NOD) on this conversion factor because, in addition to converting ammonia to nitrate, microbes also use some ammonia in protein synthesis. The net effect is that the ratio of oxygen consumed to ammonia removed is depressed slightly from the hypothetical value of 4.57. Values of 4.2 (Gaudy and Gaudy 1980, cited in Thomann and Mueller 1987[12]), 4.3 (Metcalf and Eddy 1991[13], p 431) and 4.33 (Bowie et al. 1985[14], EPA rate constants) have been reported. The present version of the Segment 15 Water Quality Model uses 4.3. The conversion ratio affects DO predictions directly through NOD and indirectly through calculations of SOD.

The conversion of ammonia to nitrate can be estimated from the rate of disappearance of ammonia. When the rate of disappearance of ammonia is estimated, however, any processes leading to the internal regeneration or uptake of ammonia must be accounted for. The model incorporates an allowance for uptake of ammonia via algal

[12] Thomann, R.V. and J.A. Mueller. 1987. Principles of Surface Water Quality Modeling and Control. Harper & Row. New York.

[13] Metcalf & Eddy, Inc. Revised by Tchobanoglous, G. and F. L. Burton. 1991. Wastewater Engineering Treatment Disposal Reuse. McGraw-Hill Publishing Company. New York.

growth based on rate of photosynthesis. In other words, the production of a fixed amount of organic matter through the photosynthetic process corresponds to the uptake of a specific amount of ammonia, which is the source of nitrogen preferred by algae for synthesis of protein. In addition, SOD (microbial respiration in sediments) is assumed to liberate ammonia at a rate reflected by the ratio of nitrogen to carbon in organic matter. CBOD, a similar process occurring in the water column, is not assumed to liberate ammonia. Some of the ammonia liberated by CBOD and SOD processes is incorporated into microbial biomass and passes downstream in particulate form. If both CBOD and SOD were assumed to liberate all of the ammonia released by their catabolic processes, loss of ammonia to microbial biomass would not be reflected. Therefore, as an approximation, SOD is assumed to generate ammonium stoichiometrically while CBOD is not. Errors inherent in these assumptions and simplifications are not likely to affect estimates of nitrification where ammonia is present at relatively high concentrations (>1 mg/L). Errors could become more important downstream, in MSP Segment 1, but insufficient information is available at this time to provide a basis for judging conversion rates of organic nitrogen to inorganic nitrogen.

Denitrification, the process by which nitrate, under anoxic conditions occurring in the hyporheic zone, is converted to dinitrogen (N_2) through microbial action, is included in the model. Estimation of rates for denitrification assumes that the rate of disappearance of nitrate in the downstream direction, when corrected for the generation of nitrate through the nitrification process, reflects the process of denitrification.

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[14] Bowie, G. L. et al. 1985. Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling. U.S. Environmental Protection Agency. Athens, GA.

Transformation Rates in the Segment 15 Water Quality Model: Calibration and Validation

Rates for processes defined in the model were estimated from field data during model calibration as described below. Calibration depends on independent estimates of reaeration (described in the section on reaeration and accurate hydrologic data. Transformation rates vary spatially, but for low flow are assumed to be constant at a given location over time after adjustment to 20°C.

Selection of Calibration Data Sets

Diel studies provide the information necessary for estimating the rates of transformations. For reasons explained in a previous section, diel studies conducted prior to 1995 are excluded from recalibration because community respiration showed a trend over time prior to 1995. Sixteen diel studies were conducted between 1995 and 2001. Four of these were excluded because spatial coverage was incomplete (August 1996 and all three studies in 1998). These studies had special objectives that required a high degree of spatial resolution covering only a part of the usual geographical area. In addition, the study conducted in July 1999 was excluded because flow was very high (>1000 cfs at Henderson), calling into question the applicability of results to low-flow conditions of regulatory interest. The remaining 11 studies were sub-sampled at random to identify four sets to be used in model validation (September and October 1995, September and October 1997). The other seven diel studies were used to calibrate the model.

Calibration Procedure

For each diel study, a separate calibration spreadsheet was built around the latest version of the Segment 15 Water Quality Model. Records from the USGS, SEO, and the various dischargers defined the hydrologic conditions on each date, and model calculations for flow were checked against gages. Rates for photosynthesis and community oxygen demand were estimated in an analysis of diel oxygen data. Observed temperatures were used to set longitudinal patterns of change so that ambient conditions were represented as accurately as possible. Daily average concentrations for constituents at each sampling site along the South Platte provided targets to be used in estimating rates. Nitrification rates were adjusted iteratively for each of three reaches (above 88th, 88th to Henderson, Henderson to Road 28) to minimize deviations between the observed and modeled concentrations of total ammonia. A similar procedure then was applied to nitrate to produce an estimate of denitrification rate. The removal of CBOD was then estimated for the same three reaches by iteration. Sediment oxygen demand was calculated for each reach in the model as the difference between total observed demand and the combined demand of CBOD removal, algal oxygen demand, and nitrification.

Results of Calibration

The analysis of diel oxygen data yielded rates for photosynthesis at each of the sites sampled during the diel studies (Table 26). The same analysis produced rates for community oxygen demand (Table 27). Community oxygen demand was not estimated at 104th Avenue, however, because oxygen concentrations were elevated there due to proximity of the sampling site to the Fulton drop structure. For all sites, rates showed no obvious spatial or temporal pattern.

Site	Sep 96	Oct 96	Feb 99	Nov 99	May 00	Oct 00	Mar 01	Median	s.e.
64th Avenue	0.00109	0.00109	0.00251	0.00136	0.00077	0.00257	0.00406	0.00136	0.00045
78th Avenue	0.00090	0.00126	0.00125	0.00230	0.00056	0.00147	0.00207	0.00126	0.00023
88th Avenue	0.00075	0.00055	0.00122	0.00143	0.00034	0.00102	0.00143	0.00102	0.00016
McKay	0.00044	0.00061	0.00093	0.00097	0.00032	0.00084	0.00145	0.00084	0.00014
104th Avenue	0.00039	0.00035	0.00000	0.00052	0.00004	0.00048	0.00132	0.00039	0.00017
124th Avenue	0.00038	0.00063	0.00085	0.00264	0.00029	0.00126	0.00216	0.00085	0.00034
160th Avenue	0.00031	0.00069	0.00060	0.00208	0.00022	0.00133	0.00197	0.00069	0.00029
Road 8	0.00046	0.00034	0.00118	0.00146	0.00025	0.00107	0.00123	0.00107	0.00019
Fort Lupton	0.00027	0.00034	0.00100	0.00110	0.00034	0.00098	0.00085	0.00085	0.00014
Road 18	0.00027	0.00034	0.00090	0.00160	0.00039	0.00133	0.00077	0.00077	0.00019
Road 28	0.00027	0.00046	0.00052	0.00123	0.00019	0.00081	0.00077	0.00052	0.00014

Table 26. Estimates of primary production (gO_2/W/d at 20°C) from diel studies selected for model calibration. The median and standard error of the mean (s.e.) are also given for each location.

Site	Sep 96	Oct 96	Feb 99	Nov 99	May 00	Oct 00	Mar 01	Median	s.e.
64th Avenue	1.14	3.36	13.18	9.59	7.28	8.21	12.52	8.21	1.68
78th Avenue	7.24	12.14	21.37	20.53	12.97	14.55	19.98	14.55	1.99
88th Avenue	5.78	7.26	12.63	13.41	8.73	9.12	12.04	9.12	1.09
McKay	5.18	6.90	10.59	9.15	7.88	8.33	11.49	8.33	0.81
124th Avenue	9.77	12.34	22.36	24.98	12.30	15.06	17.79	15.06	2.13
160th Avenue	9.32	14.37	19.44	19.80	10.28	12.95	17.07	14.37	1.59
Road 8	11.32	11.96	20.17	19.53	9.37	12.38	15.94	12.38	1.59
Fort Lupton	10.60	11.09	20.59	17.68	10.08	12.15	16.40	12.15	1.55
Road 18	11.65	17.66	33.05	25.70	12.48	13.29	25.72	17.66	3.13
Road 28	8.57	15.31	33.96	19.71	2.93	9.53	25.77	15.31	4.08

Table 27. Estimates of community oxygen demand (gO_2/m^2/d at 20°C) from diel studies selected for model calibration. The median and standard error of the mean (s.e.) are given for each location.

Nitrification rates, which are shown in Table 28, tend to increase with distance from Metro, but no clear pattern was evident in the rates of denitrification (Table 29).

Site	Sep 96	Oct 96	Feb 99	Nov 99	May 00	Oct 00	Mar 01	Median	s.e.
Above 88th	0.01	3.08	0.31	2.26	0.30	0.50	0.01	0.31	0.46
88th to Henderson	0.09	2.09	2.85	4.30	1.50	2.67	1.38	2.09	0.50
Henderson to Rd 28	2.76	2.20	2.94	3.17	1.32	2.85	2.64	2.76	0.23

Table 28. Nitrification rates ($gN/m^2/d$ at 20°C) from diel studies selected for model calibration.

Site	Sep 96	Oct 96	Feb 99	Nov 99	May 00	Oct 00	Mar 01	Median	s.e.
Above 88th	0.01	1.22	0.00	0.00	0.51	0.55	0.22	0.22	0.17
88th to Henderson	0.01	0.53	0.75	0.22	0.39	0.96	0.59	0.53	0.12
Henderson to Rd 28	0.20	0.51	0.25	0.10	0.36	0.68	0.83	0.36	0.10

Table 29. Denitrification rates (d^{-1} at 20°C) from diel studies selected for model calibration.

Removal of CBOD (Table 30) may occur through decay, which occurs through the entire length of the segment, and settling, which is most likely near the effluent discharge. Settling was indicated in the data as a difference between expected respiration rates based on downstream data and observed decline in CBOD near Metro. It was detectable only as far downstream as Clear Creek (about 1.7 miles below Metro's outfall), and only on certain dates. Documentation for specific settling rates was not available, however. For

Site	Sep 96	Oct 96	Feb 99	Nov 99	May 00	Oct 00	Mar 01	Median	s.e.
Above 88th	0.01	1.58	0.52	1.93	2.60	2.88	1.87	1.87	0.39
88th to Henderson	1.91	1.39	1.83	2.11	3.72	1.50	1.03	1.83	0.33
Henderson to Rd 28	1.63	1.31	0.53	1.06	2.67	1.55	1.00	1.31	0.25

Table 30. Decay rate (d^{-1} at 20°C) for dissolved CBOD as determined from diel studies selected for model calibration. An additional reach is defined for the South Platte above Sand Creek 10.1 mile below the Metro discharge for which the rate is set at 0.11 d^{-1} based on earlier studies.

present modelling the rate was set at 14 per day, but the rate should be better documented for future modelling. The rate was applied to the reach between the Metro District outfall and a point on the South Platte River just above Clear Creek. If the rate is substantially lower than presently assumed, an aeration structure just above the Fulton Ditch would likely be required.

Over the very short distance between Sand Creek and the Metro outfall (0.1 miles), the CBOD removal rate is set at 0.11 d^{-1} based on previous studies by the Metro District rather than the value shown in Table 30.

Community oxygen demand often exceeds the sum of nitrification, algal respiration, and CBOD decay on a given date at a given location. As mentioned above, the residual demand is assumed to be sediment oxygen demand (SOD). Table 31 shows SOD estimates for selected locations. Rates showed some evidence of seasonality, and thus are set separately for warm (June-October) and cool (November-May) months. Negative residuals are set to zero.

Location	River Miles	Dates							Warm Weather		Cool Weather	
		Sep 96	Oct 96	Feb 99	Nov 99	May 00	Oct 00	Mar 01	Median	s.e.	Median	s.e.
64th Avenue	312.37	0.01	0.00	9.13	0.00	4.92	3.66	8.85	0.01	1.22	6.89	2.14
78th Avenue	310.16	4.54	0.00	8.35	0.00	0.51	0.68	2.44	0.68	1.41	1.48	1.91
88th Avenue	308.62	2.20	0.00	0.00	0.00	0.00	0.00	3.45	0.00	0.73	0.00	0.86
McKay Road	306.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
104th Avenue	305.24	7.50	1.32	0.00	0.00	1.08	0.00	2.58	1.32	2.31	0.54	0.61
124th Avenue	300.98	0.49	3.39	1.41	0.15	6.80	0.93	1.21	0.93	0.90	1.31	1.49
160th Avenue	295.20	0.00	3.60	6.28	4.61	3.66	0.00	3.35	0.00	1.20	4.14	0.66
Road 8	290.13	0.00	1.57	6.50	4.68	2.79	0.00	2.74	0.00	0.52	3.74	0.90
Fort Lupton	287.19	0.00	0.69	6.98	3.07	3.33	0.00	3.36	0.00	0.23	3.35	0.93
Road 18	283.69	0.00	6.99	18.56	10.36	5.60	0.00	12.20	0.00	2.33	11.28	2.68
Road 28	277.50	0.00	4.76	19.66	4.98	0.00	0.00	12.38	0.00	1.59	8.68	4.30

Table 31. Sediment oxygen demand ($gO_2/m^2/d$ at 20°C) as estimated for the calibration data sets.

Validation

Four diel data sets were reserved for evaluation of rates defined in model calibration. Spreadsheets identical to those used for calibration were created for validation, except that median rates from the calibration sets were used for each process. Performance was assessed in terms of predicted versus observed concentrations for the modeled constituents (Table 32, Figure 11). Model performance was excellent for the

Constituent	Slope	Intercept	r^2
Ammonia	1.07	0.07	0.98
Nitrate	1.05	-0.25	0.89
CBOD	1.02	-0.46	0.89
Oxygen	1.07	0.00*	0.32

* Intercept set to zero because estimates are based in part on residuals.

Table 32. Summary of validation results expressed in terms of linear regression in which observations are the independent (x-axis) values.

three constituents for which rates are based solely on observed changes in concentration (ammonia, nitrate, CBOD). Predictions were more variable but still acceptable for dissolved oxygen, which is subject to greater error because it requires simultaneous prediction of several processes that consume or generate oxygen. Oxygen predictions showed no significant bias, however (slope . 1.0).

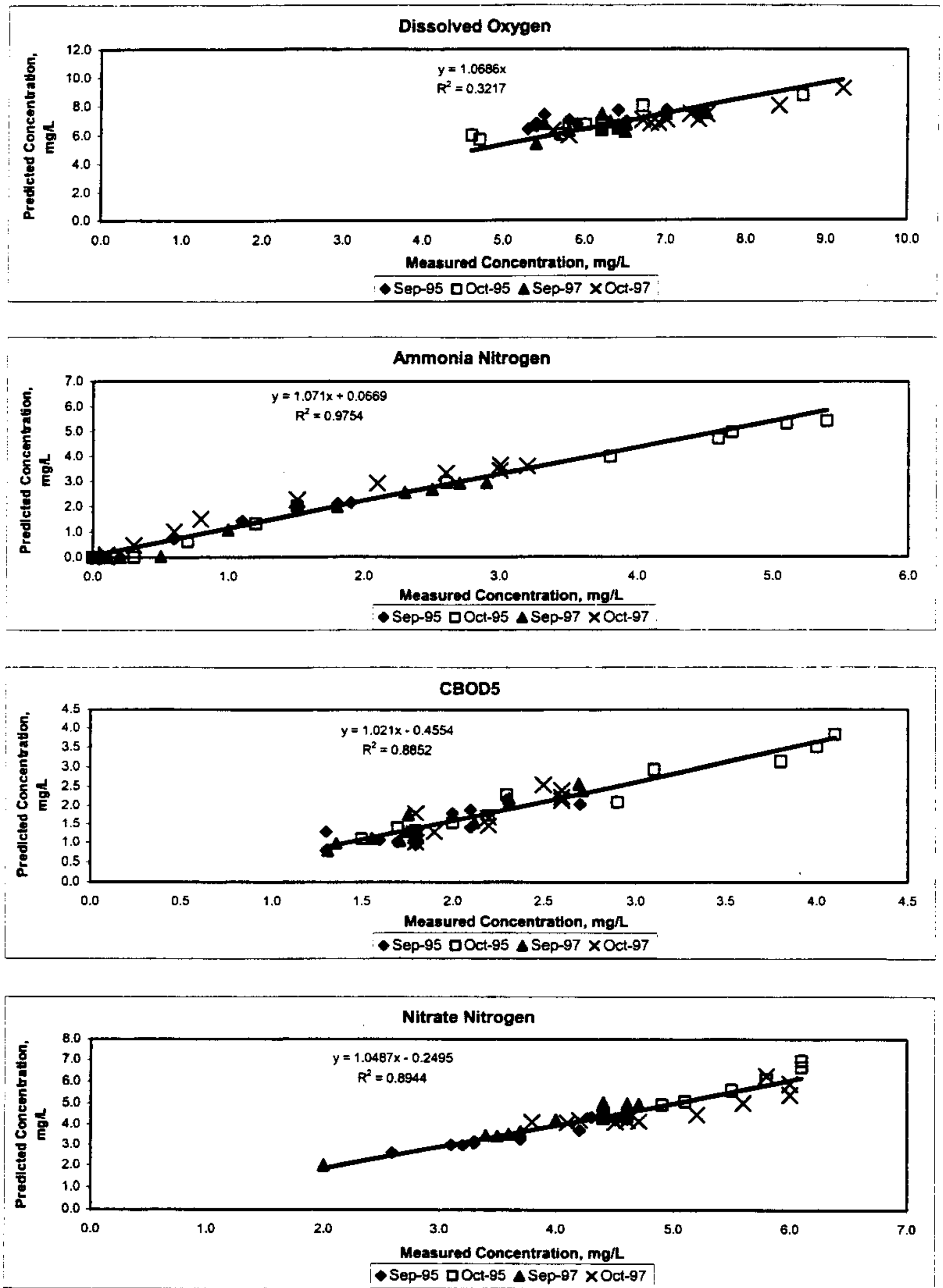


Figure 11. Results of the validation.

Standards for Ammonia and Dissolved Oxygen in the Segment 15 Water Quality Model

The chronic standard for ammonia in Segment 15 and MSP Segment 1 is 0.100 mg/L unionized, as N. The acute standard is computed from pH and temperature as specified in Colorado's Basic Standards for warmwater aquatic life.

Stream standards for dissolved oxygen in Segment 15, which have evolved substantially during the last five years, are complex (Table 33). In contrast, the standard applicable to the Middle South Platte is simply 5 mg/L in all months.

Type	Interval	Type	Months	Amount
ELS	1-d	Minimum	April-July	3.0
OLS	1-d	Minimum	August-March	2.0
ELS	7-d	Mean	April-July	5.0*
OLS	7-d	Minimum Mean	August-March	2.5
OLS	30-d	Mean	August-March	4.5

* 4.5 mg/L north of Lupton Bottom

Table 33. Dissolved oxygen standards for Segment 15 of the Upper South Platte River. Temporary modifications (not shown) apply to reaches south of the Brighton diversion until 1 Nov 2004 (not included in modelling). Standards are distinguished on the basis of averaging interval and life history stage (ELS = early life stage of fish; OLS = older life stage of fish).

When acute conditions are specified on the control page of the model, predictions of minimum dissolved oxygen are plotted as model output. The 1-d minimum is taken as identical to the 7-d mean of minima (this is a conservative assumption, but meaningful differences are unlikely). The 1-d standard is 3.0 mg/L for the months April through July, when early life stages require protection. In other months, the 1-d standard is 2.0 mg/L.

The graphs produced by the model show the Segment 15 acute standards to the MSP Segment 1 for modelling, even though no such standards have yet been adopted.

The model also predicts daily average dissolved oxygen for chronic low-flow conditions. The results are applied both to the 7-d and 30-day standards; significant differences are unlikely. Accordingly, the model uses 5.0 mg/L as a chronic standard when ELS are present and 4.5 mg/L when they are not. North of the Lupton Bottom diversion, the standard is 4.5 mg/L (Table 33). The chronic standards defined for Segment 15 are extended into the MSP Segment 1 in the model.

Structural Changes to the Segment 15 Water Quality Model

The model has been extensively renovated. The new organization of the various pages that constitute the model and its supporting data sets reflects experience with the model over the last 10 years. It is now easier to locate and modify inputs and to make predictions for hypothetical conditions. In addition, there have been some minor modifications to reaches in the model, as described below. Full operation of the model has been extended to reaches from Fort Lupton to Road 28, and predictions of dissolved oxygen are for the first time possible for all months of the year.

The easiest way to describe the new layout is with a table listing the pages and their contents (Table 34). Chief improvements include a complete reorganization of input variables and a simplified control panel with new graphs. The only major element that has been deleted is the capacity to alter reach dimensions on a broad scale. It is still feasible to alter the dimensions of any reach, but it is more difficult to change channel dimensions. The change was made because no use has been made of dimensional flexibility in previous version of the model.

Channel dimensions have been changed at two locations in Segment 15 as a result of new drop structures that have been constructed near 104th Avenue and 124th Avenue. The structure downstream of 104th Avenue was completed in October 2000, and the structure downstream of 124th Avenue was completed in January 2002. The

Page Name	Contents	Comments
Controls	Graphs and switches	Set conditions including month standard, regional facility, etc. Observe output.
Model	Reach model calculations	Longitudinal profiles of all constituents are created on the basis of inputs, diversions, and transformations defined on other pages.
Metro Effluent	NFE and SFE chemistry	Historical conditions or expected characteristics are listed for each complex, and provide the basis for the combined characteristics defined on other pages.
Biol Rates	Transformation rates	Community metabolism, nitrification, denitrification, CBOD removal, and sediment oxygen demand rates are defined on this page.
K2	Reaeration rates	Measured or estimated reaeration rates are listed for stream reaches (K2) and drop structures (E20). Lookup tables are available for proposed structures.
Flows	Low flows, design flows, seepage	Acute and chronic low flows are listed for "headwaters," tributaries, and diversions. Design flows are shown for each WWTP, and seepage rates are defined monthly for each of three reaches.
Temperature	Temperature inputs	Defined monthly for each of 9 sources.
pH	pH inputs	Defined monthly for each of 9 sources.
Oxygen	DO inputs	Defined monthly for each of 9 sources.
CBOD	CBOD inputs	Defined monthly for each of 9 sources.
Ammonia	Ammonia inputs	Defined monthly for each of 9 sources. Special calculations apply to Sand Creek.
Nitrate	Nitrate inputs	Defined monthly for each of 9 sources.
Setpoint	Acute and chronic setpoints	Defined monthly for acute and chronic conditions at each of five locations.

Table 34. Organization and description of spreadsheet pages that comprise the Segment 15 Water Quality Model.

location and dimensions of each structure were taken from construction drawings provided by CDM. Stream width is represented as the full length of the weir crest even though the weirs are installed on a bias. This is necessary to assume that calculations of water depth are correct in the model.

The Segment 15 Water Quality Model now extends about 11 miles downstream of Segment 15. The downstream limit of the model has been set at Road 28 for several years in anticipation of additional supporting data. Field data obtained recently by the Metro District now make it possible to supply all of the necessary data on water quality constituents as far as Road 28, but documentation of reaeration rates and hydrology is still inadequate below Segment 15. Spatial extension of the model is desirable in terms of reaching conclusions about the longitudinal extent of Metro's influence and in making predictions about effects of a proposed regional facility near Brighton.

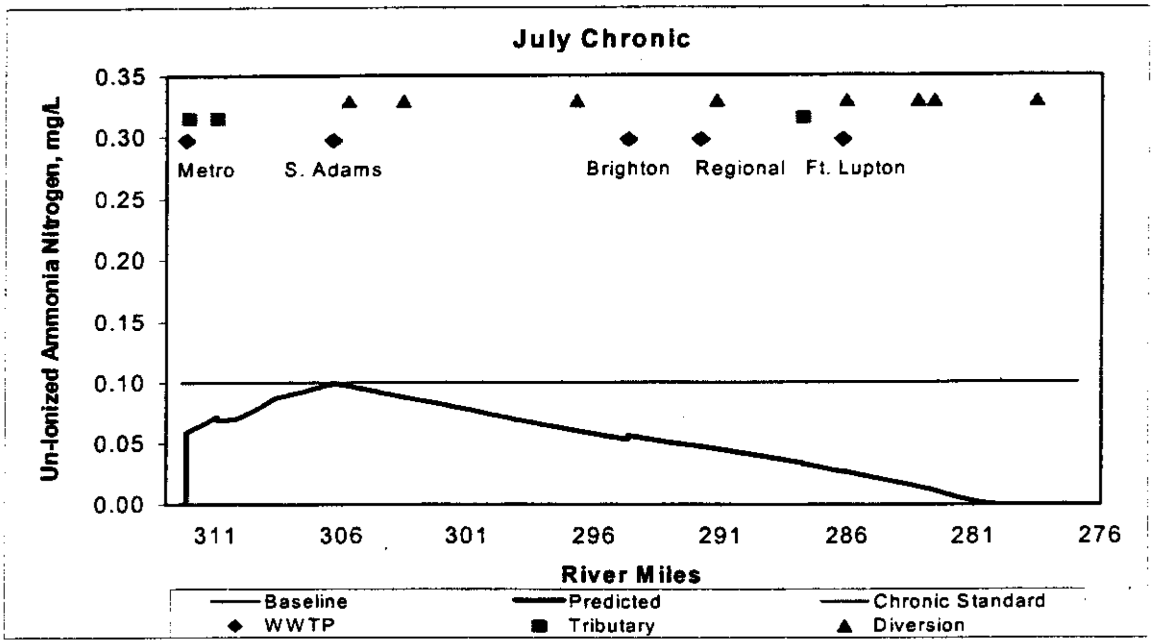
Possible locations for a new regional facility have been added to the model (see below).

Projected Effluent Limits

The predicted amounts of unionized ammonia and dissolved oxygen in Segment 15 and in upper MSP Segment 1 can be adjusted through changes in the concentrations of total ammonia in the Metro District's effluent. Adjustments necessary to meet the standards for unionized ammonia and oxygen are the basis for selection of the projected effluent limits for the Metro District. The adjustments were made in two stages: first for unionized ammonia and then for dissolved oxygen.

As expected, the concentrations of unionized ammonia in the South Platte River rise to a peak over a distance of several miles and then decline steadily beyond the peak at greater distances from the outfall (Figure 12, Appendix A). The peak defines the critical point, i.e., the point on the river that serves as a direct constraint on the total ammonia in Metro's effluent in any given month.

Figure 12 shows the rise and fall of concentrations of unionized ammonia along the South Platte River below Metro's outfall. Significant points on the graph include the rise in unionized ammonia concentration that occurs at the point of the Metro outfall, an increase in this concentration typically over about five miles (with some variation between months), and a steady decline with some irregularities reflecting the addition of small amounts of effluent by downstream dischargers. Changes in the amount of unionized ammonia below Metro are explained mostly by changes in pH and temperature, which affect the percentage of total ammonia that is unionized, by nitrification, which removes total ammonia, and by dilution. These processes have opposing effects on the concentrations of unionized ammonia; pH tends to increase with distance downstream, which raises the percent unionized ammonia, but nitrification and dilution steadily reduce the concentrations of total ammonia. Thus the critical point typically occurs a few miles downstream of Metro, but there is some variation between months because of differences in hydrologic conditions, pH, and nitrification rates. As shown by Figure 12 and graphs for other months (Appendix A), the small discharges below Metro have little effect on the effluent limits that are applicable to Metro.



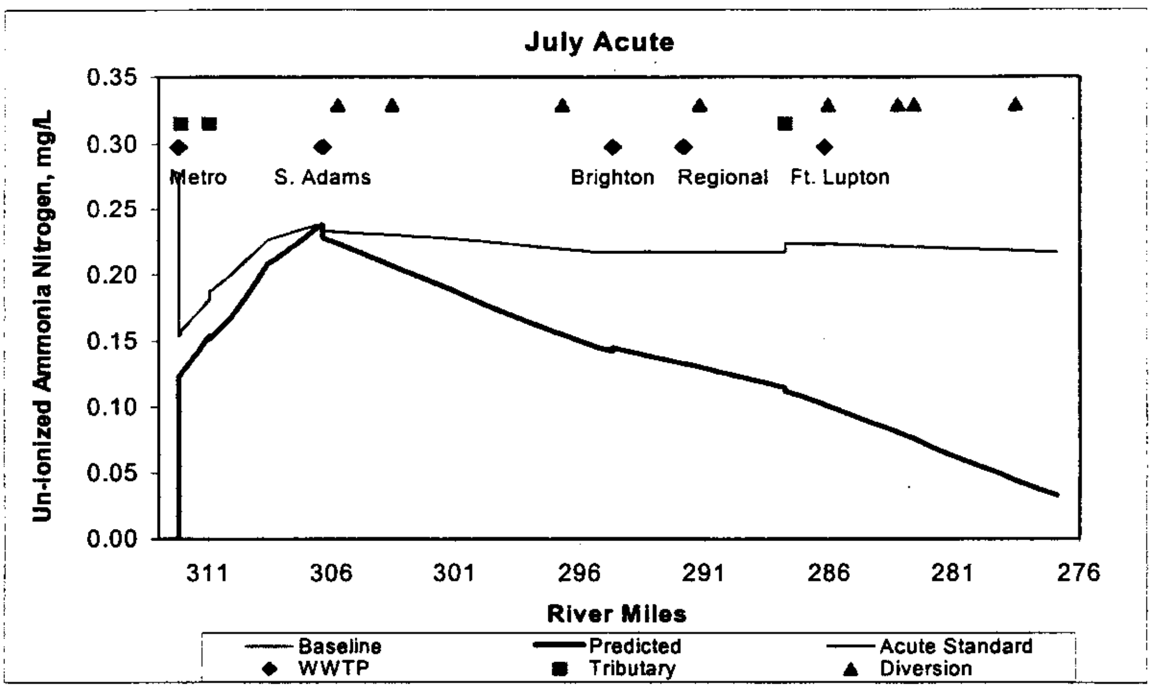


Figure 12. Modelling results for July (unionized ammonia) based on effluent concentrations shown in Table 35. Concentrations for the Metro effluent have been adjusted as necessary to bring Segment 15 to the compliance points for chronic and acute standards.

Figure 12 applies only to the month of July. From similar graphs in other months of the year, maximum allowable concentrations of total ammonia for acute and chronic conditions can be identified (graphs shown in Appendix A), and these are listed in Table 35, with truncation of limits at a maximum of 25 mg/L for chronic conditions and 30 mg/L for acute conditions. Chronic limits are then adjusted down to match current limits in all months except August, for which modelling indicates the need for a limit lower than the current one (there are no current acute effluent limits). These are the projected effluent limits for total ammonia based on compliance with the standard for unionized ammonia.

	Metro			South Adams		Brighton	
Month	Chronic*	Chronic Adjusted**	Acute	Chronic	Acute***	Chronic	Acute***
January	25.0	15.0	30.0	25.0	-	25.0	-
February	25.0	15.0	30.0	25.0	-	25.0	-
March	25.0	14.0	26.6	25.0	-	25.0	-
April	20.4	14.0	25.6	25.0	-	25.0	-
May	21.5	13.0	25.9	25.0	-	25.0	-
June	20.0	13.0	27.0	25.0	-	25.0	-
July	10.3	10.0	21.5	25.0	-	25.0	-
August	9.7	9.7	23.4	25.0	-	25.0	-
September	16.5	10.0	26.7	25.0	-	25.0	-
October	15.4	10.0	23.4	25.0	-	25.0	-
November	20.2	14.0	24.1	25.0	-	25.0	-
December	25.0	15.0	27.8	25.0	-	25.0	-

* Cap at 25 mg/L chronic, 30 mg/L acute.
**Modeled concentrations that are higher than current permit and have been adjusted down to match current permit concentrations.
***Acute limits not needed for these small dischargers.

Table 35. Monthly concentrations of total ammonia in effluent that would be consistent with standards for unionized ammonia in Segment 15, as shown by the Segment 15 Water Quality Model. Table 16 shows assumed concentrations for all other ammonia sources.

The second step in the projection of effluent limits is to determine whether or not the projected limits based on unionized ammonia alone allow compliance with the oxygen standard. Projected concentrations of dissolved oxygen in the South Platte are dependent on assumptions about the amount of oxygen in effluents, the CBOD of effluents, and the ammonia content of effluents. Any correlations between these variables must be taken into account. For example, if CBOD and total ammonia content of effluents happen to be correlated as shown by monitoring data, the model would need to anticipate that the assumption of a high total ammonia concentration in the effluent would be accompanied by a high CBOD. Alternatively, if the variables are not correlated at all, projections involving extremes for any one variable should be based on the assumption of the median value for the other variables.

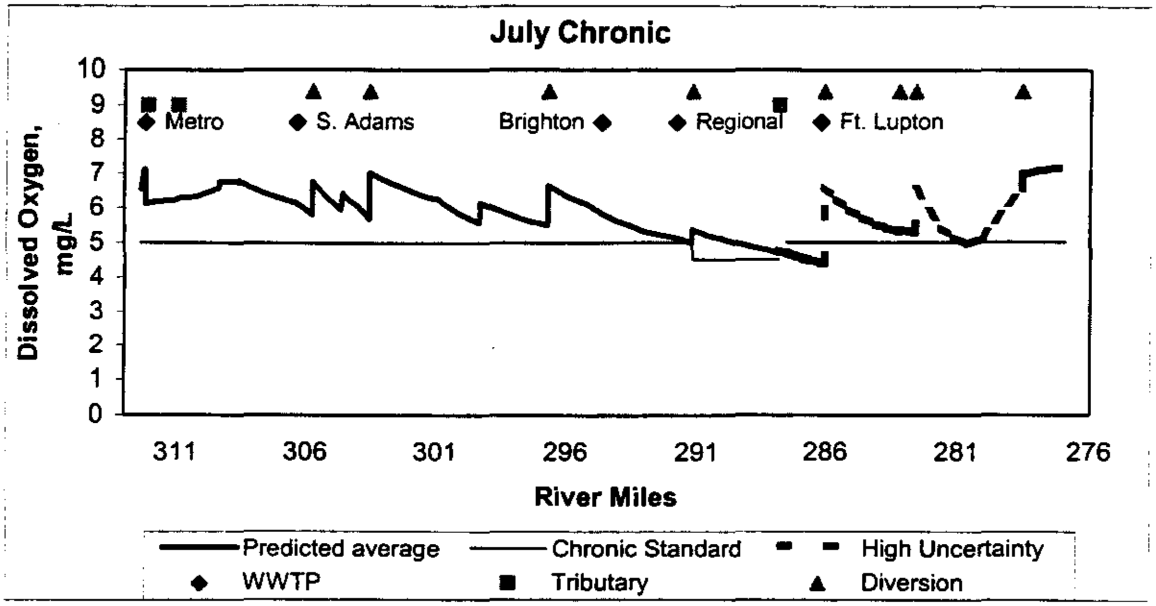
A statistical study of relationships between total ammonia, CBOD, and dissolved oxygen in the Metro effluent shows that there are no statistical relationships among these variables (Appendix C). Thus, when oxygen concentrations are projected in relation to total ammonia, the expected values for dissolved oxygen in the effluent and CBOD in the effluent are set to characteristic values (medians). The process is repeated when limits are developed for CBOD and for dissolved oxygen. Values for the other effluents are set to typical values prior to manipulation of modeled concentrations for Metro's effluent as necessary to find appropriate effluent limits.

July produces the most extreme conditions for dissolved oxygen with respect to the standards applicable to USP Segment 15. Figure 13 shows the modelling results for July with total ammonia set on the basis of the need for compliance with the unionized ammonia standard. No months other than July are predicted to show oxygen below the standards in USP Segment 15. Excursions below the standard are predicted for May through July in MSP Segment 1 (Appendix B), although confidence in these predictions is low because little information is available on MSP Segment 1.

Figure 13 shows for July a black line extending down to a point just above Big Dry Creek (Big Dry Creek marks the end of the segment), and a dashed line from that point down to Road 28. The dashed line indicates that oxygen concentrations are predicted with much less certainty below Segment 15 than within Segment 15. As explained previously, predictions for MSP Segment 1 are hampered by the unavailability of sufficient information on reaeration and hydrology. While steps are being taken to obtain this additional information, the current modelling results must be designated as provisional for MSP Segment 1. For Segment 15 itself, the results are much more secure because the underlying data are more extensive.

As shown by Figure 13, the oxygen curve for July dips below the allowable minimum concentration for chronic conditions at a point just above the Lupton Bottom ditch. With less certainty, the model also predicts inconsistency with both the chronic and acute standards in MSP Segment 1.

Figure 13 indicates the need for a plan to increase, by an amount less than 1 mg/L, the dissolved oxygen concentration in the lowermost portion of Segment 15. Accomplishment of this goal by removal of ammonia from the Metro District's effluent would be quite difficult because it would require large increments of ammonia removal. Because the affected reach is relatively short, a more likely possibility, which



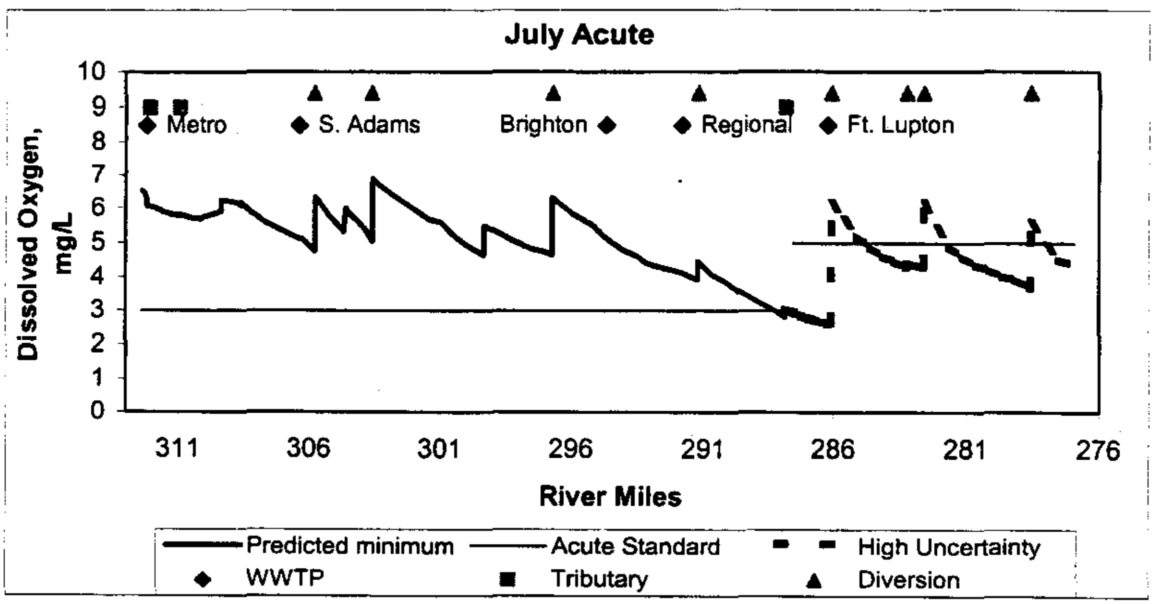


Figure 13. Modelling results for July (dissolved oxygen) based on effluent concentrations shown in Table 35.

would need to be approved by the State, is introduction of a means of aeration at a point above the headgate of the Lupton Bottom ditch. Effects of structural changes similar to those previously constructed elsewhere on Segment 15 are shown in Figure 14.

In summary, assuming that an aeration structure or other means of adding a small amount of oxygen to Segment 15 above Lupton Bottom ditch can be arranged, the effluent limits for ammonia shown in Table 35 are suitable for compliance with the standards for unionized ammonia and dissolved oxygen on the South Platte below the Metro District.

A second consideration for dissolved oxygen is CBOD. Following the rationale described above, total ammonia is set to characteristic values (Table 16) and the same is done for dissolved oxygen in the effluent. The CBOD concentrations in the Metro effluent then are adjusted to the compliance limits for oxygen in the stream. If there is any indication of interaction between the limits developed through modelling for Metro and the current permit limits for South Adams and Brighton, the limits for South Adams and Brighton are adjusted as needed to achieve a reasonable allocation among the dischargers. The results of modelling for CBOD are reported in Table 36.

The same modelling approach that was used for CBOD is used in developing limits for dissolved oxygen in effluent. The results are reported in Table 37.

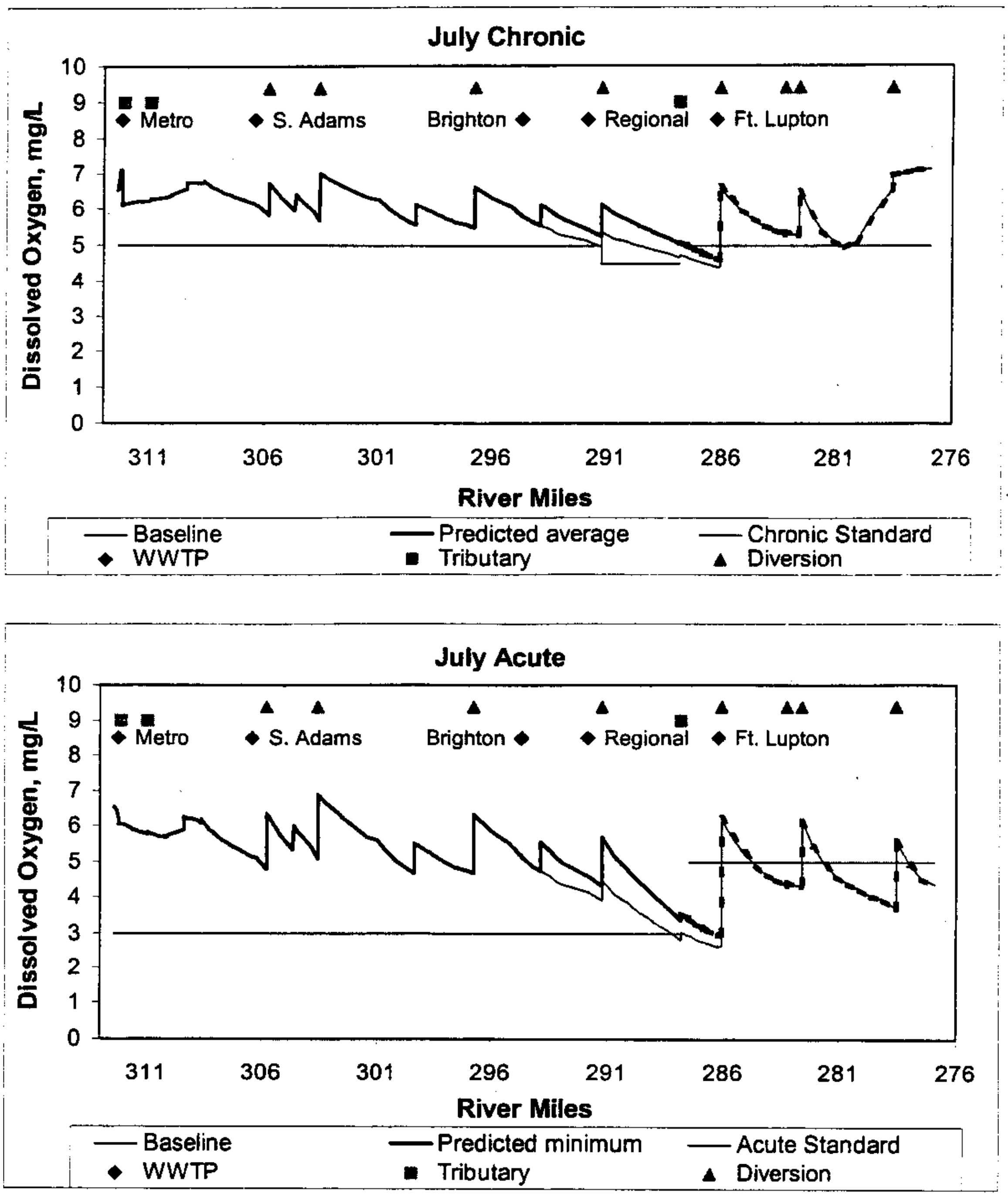


Figure 14. Effect of hypothetical structural changes on oxygen concentrations near the end of Segment 15 (2 foot dam 3 miles above Lupton Bottom, raise Lupton Bottom dam to 3 feet).

Month	Metro		South Adams*		Brighton*	
	Chronic	Acute	Chronic	Acute	Chronic	Acute
January	17.0	30.0	25.0	-	25.0	-
February	17.0	30.0	25.0	-	25.0	-
March	17.0	30.0	25.0	-	25.0	-
April	17.0	30.0	25.0	-	25.0	-
May	17.0	30.0	25.0	-	25.0	-
June	17.0	30.0	25.0	-	25.0	-
July	17.0	30.0	25.0	-	25.0	-
August	17.0	30.0	25.0	-	25.0	-
September	17.0	30.0	25.0	-	25.0	-
October	17.0	30.0	25.0	-	25.0	-
November	17.0	30.0	25.0	-	25.0	-
December	17.0	30.0	25.0	-	25.0	-

*Acute limits not needed for these small dischargers; acute set to chronic for modelling runs.

Table 36. Monthly concentrations of CBOD (cap set at 17 mg/L chronic, 30 mg/L acute for Metro) in effluent for the dischargers that would be consistent with standards for oxygen in USP Segment 15, as shown by the Segment 15 Water Quality Model.

Month	Metro		South Adams		Brighton	
	Chronic	Acute	Chronic	Acute	Chronic	Acute
January	4.5	2.0	4.5	-	4.5	-
February	4.5	2.0	4.5	-	4.5	-
March	4.5	2.0	4.5	-	4.5	-
April	5.0	3.0	5.0	-	5.0	-
May	5.0	3.0	5.0	-	5.0	-
June	5.0	3.0	5.0	-	5.0	-
July	5.0	3.0	5.0	-	5.0	-
August	4.5	2.0	4.5	-	4.5	-
September	4.5	2.0	4.5	-	4.5	-
October	4.5	2.0	4.5	-	4.5	-
November	4.5	2.0	4.5	-	4.5	-
December	4.5	2.0	4.5	-	4.5	-

* Acute limits not needed for these small dischargers; acute set to chronic for modelling runs.

Table 37. Monthly concentrations of dissolved oxygen (mg/L) in effluent limits for the dischargers that would be consistent with standards for dissolved oxygen on Segment 15, as shown by the Segment 15 Water Quality Model.

Inclusion of a Regional WWTP in the Segment 15 Water Quality Model

Three wastewater treatment facilities discharge directly to the South Platte between the Metro outfall and Road 28 (South Adams, Brighton, Fort Lupton). The basis for modelling contributions from these facilities is outlined in previous sections of this report. Some of the information is repeated here as context for estimated characteristics of a planned regional treatment facility that would be located downstream of Brighton (see Figure 1 for three possible locations). Characteristics of the regional facility, which will use an extended aeration process with nitrification and denitrification, are based on information supplied by Carl Houck of Carollo Engineers. Flows are as shown in Table 38.

	Year			
Source	2007	2010	2015	2020
Metro*	4.4	5.4	6.05	6.6
South Adams	2.0	2.8	4.3	5.8
Brighton	2.7	3.0	3.6	4.4
Total, New Facility	9.2	11.1	14.0	16.8

*Includes Todd Creek.

Table 38. Proposed diversions of effluent to a new regional wastewater facility near the bottom of Segment 15.

Monthly median temperatures are shown in Table 39 for the three existing facilities; the values for Fort Lupton are set equal to Metro's combined effluent, which is very similar to midpoints of monthly extremes as reported in the Fort Lupton DMRs. Information regarding the regional facility indicates an influent temperature ranging over the year from 12°C to 21°C. With some cooling in the winter and some warming during the summer through the WWTP, 10°C to 22°C would be the likely effluent range.

Inspection of data from the other three facilities shows that South Adams has a temperature range very similar to the estimated range. Therefore, temperature in the effluent of the proposed regional facility is set equal to that of the South Adams facility.

Selection of pH was more difficult than selection of temperature because pH is influenced by process changes. The values listed for Metro, South Adams, and the regional facility reflect expected performance (Table 40). For Metro, only a combined value is available; North and South complex pH values are not available separately. The values listed for Brighton are consistent with previous modelling related to the South Adams and Brighton facilities. Recent historical values for Brighton are lower by a few tenths. Values shown for Fort Lupton are midpoints of the monthly extremes reported in

Month	Metro combined	South Adams WWTP	Brighton WWTP*	Fort Lupton WWTP	Regional WWTP
Jan	15.6	11.1	10.6	15.6	11.1
Feb	15.3	13.3	10.0	15.3	13.3
Mar	16.0	12.2	11.1	16.0	12.2
Apr	16.6	14.4	14.4	16.6	14.4
May	18.4	16.1	17.8	18.4	16.1
Jun	20.1	18.9	17.2	20.1	18.9
Jul	22.0	22.2	20.0	22.0	22.2
Aug	23.0	22.2	20.0	23.0	22.2
Sep	22.7	22.2	19.4	22.7	22.2
Oct	21.0	17.8	17.2	21.0	17.8
Nov	18.8	12.2	12.2	18.8	12.2
Dec	16.6	13.3	13.9	16.6	13.3

*Flows reduced to zero by 2020.

Table 39. Monthly temperatures for WWTPs in the Segment 15 Water Quality Model. Values for the proposed regional facility are set equal to those recorded historically for the South Adams facility.

Month	Metro combined	South Adams WWTP	Brighton WWTP*	Fort Lupton WWTP	Regional WWTP
Jan	6.90	7.00	7.55	7.82	7.2
Feb	6.90	7.00	7.58	7.65	7.2
Mar	6.90	7.00	7.60	7.55	7.2
Apr	6.90	7.00	7.61	7.64	7.2
May	7.00	7.00	7.65	7.45	7.2
Jun	7.10	7.00	7.78	7.45	7.2
Jul	7.10	7.00	7.78	7.65	7.2
Aug	7.10	7.00	7.80	7.70	7.2
Sep	7.10	7.00	7.75	7.50	7.2
Oct	7.00	7.00	7.70	7.55	7.2
Nov	6.80	7.00	7.75	7.65	7.2
Dec	6.90	7.00	7.51	7.75	7.2

*Flows reduced to zero by 2020.

Table 40. Monthly characteristic pH values for WWTPs in the Segment 15 Water Quality Model. Values for the proposed regional facility are set according to expected operating conditions.

Month	Metro combined	South Adams WWTP	Brighton WWTP*	Fort Lupton WWTP	Regional WWTP
Jan	5.7	7.2	7.2	6.9	5.5
Feb	6.0	7.3	7.2	7.1	5.5
Mar	6.3	6.9	7.2	5.2	5.5
Apr	6.1	6.6	7.1	6.4	5.5
May	5.9	6.4	7.0	6.8	5.5
Jun	5.5	6.0	6.8	6.6	5.5
Jul	5.1	5.7	6.6	5.4	5.5
Aug	6.0	5.5	6.5	4.9	5.5
Sep	6.2	5.6	6.6	5.4	5.5
Oct	6.2	6.2	6.7	6.6	5.5
Nov	5.5	6.6	7.0	6.8	5.5
Dec	5.7	6.9	7.0	6.4	5.5

*Flows reduced to zero by 2020.

Table 41. Monthly characteristic concentrations for oxygen (mg/L) in effluent from WWTPs in the Segment 15 Water Quality Model. Values for the proposed regional facility are set according to the Wastewater Utility Plan.

Month	Metro combined**	South Adams WWTP	Brighton WWTP*	Fort Lupton WWTP	Regional WWTP
Jan	7.0	25.0	25.0	2.0	25.0
Feb	7.0	25.0	25.0	3.1	25.0
Mar	9.0	25.0	25.0	2.2	25.0
Apr	8.0	25.0	25.0	2.8	25.0
May	7.0	25.0	25.0	3.5	25.0
Jun	6.5	25.0	25.0	2.7	25.0
Jul	6.0	25.0	25.0	2.0	25.0
Aug	6.5	25.0	25.0	2.8	25.0
Sep	6.0	25.0	25.0	2.2	25.0
Oct	6.5	25.0	25.0	2.4	25.0
Nov	7.0	25.0	25.0	2.7	25.0
Dec	7.0	25.0	25.0	3.2	25.0

*Flows reduced to zero by 2020

**Characteristic

Table 42. Monthly concentrations for 5-day carbonaceous BOD (CBOD) in effluent from WWTPs in the Segment 15 Water Quality Model (mg/L). Values for the proposed regional facility are set according to the Wastewater Utility Plan.

recent DMRs. Values listed for the regional facility reflect expected performance given a nitrified effluent. Medians of historical data on dissolved oxygen are presented for South Adams and Brighton in Table 41. Concentrations shown for Fort Lupton are midpoints of ranges reported in the DMRs, but for a very limited set of months. Values for Metro are based on expectations about performance. Historical data were used to characterize monthly median oxygen and CBOD in the South Adams and Brighton effluents, and average concentrations from DMRs were used for Fort Lupton (Table 42). The concentrations listed for the Metro combined effluent represent expected operating conditions. Concentrations shown for the regional facility are as proposed in the Utility Plan.

Total ammonia concentrations are set as explained previously for South Adams, Brighton, and Fort Lupton (Table 43). Metro is set to concentrations that meet standards

(Table 35). The regional facility is set to conditions reflecting expected performance with nitrification (5 mg/L).

Nitrate concentrations in the first three treatment facilities are defined from historical data (Table 44). The combined value for Metro is calculated from separate sets

Month	Metro combined*	South Adams WWTP	Brighton WWTP**	Fort Lupton WWTP	Regional WWTP
Jan	25.0	25.0	25.0	5.0	5.0
Feb	25.0	25.0	25.0	5.0	5.0
Mar	25.0	25.0	25.0	5.0	5.0
Apr	20.4	25.0	25.0	5.0	5.0
May	21.5	25.0	25.0	5.0	5.0
Jun	20.0	25.0	25.0	5.0	5.0
Jul	10.3	25.0	25.0	5.0	5.0
Aug	9.7	25.0	25.0	5.0	5.0
Sep	16.5	25.0	25.0	5.0	5.0
Oct	15.4	25.0	25.0	5.0	5.0
Nov	20.2	25.0	25.0	5.0	5.0
Dec	25.0	25.0	25.0	5.0	5.0

*Set as needed to meet standards without the new regional WWTP.

**Flows reduced to zero by 2020.

Table 43. Monthly concentrations of total ammonia (mg/L) in effluent from WWTPs in the Segment 15 Water Quality Model as used in testing the effects of a new Lower South Platte Regional WWTP.

of values for the North and South complexes, which are quite different because the North complex includes a nitrification-denitrification step not present in the South complex. Values for Fort Lupton, which are very high, are taken from a very limited set of DMR data. The values listed for the regional facility are taken from the Utility Plan.

In overview, assumptions for modelling of the effects of a Lower South Platte facility are as follows: (1) Capacity wastewater flows used in modelling are as specified by Carollo Engineers for year 2020. (2) Effluent characteristics for the Lower South Platte project are assumed to be as proposed by Carollo Engineers (see preceding tables); nitrification capable of producing total ammonia not exceeding 5 mg/L is assumed. (3)

Month	Metro combined	South Adams WWTP	Brighton WWTP*	Fort Lupton WWTP	Regional WWTP
Jan	11.4	23.0	25.0	41.8	25.0
Feb	10.9	23.0	25.0	42.3	25.0
Mar	11.1	20.0	25.0	41.8	25.0
Apr	11.2	23.0	25.0	43.6	25.0
May	11.1	25.0	25.0	40.4	25.0
Jun	14.5	25.0	25.0	48.1	25.0
Jul	11.6	25.0	25.0	55.0	25.0
Aug	11.7	23.0	25.0	30.8	25.0
Sep	10.9	25.0	25.0	42.0	25.0
Oct	11.1	25.0	25.0	42.0	25.0
Nov	10.9	24.0	25.0	42.0	25.0
Dec	11.0	23.0	25.0	42.0	25.0

*Flows reduced to zero by 2020.

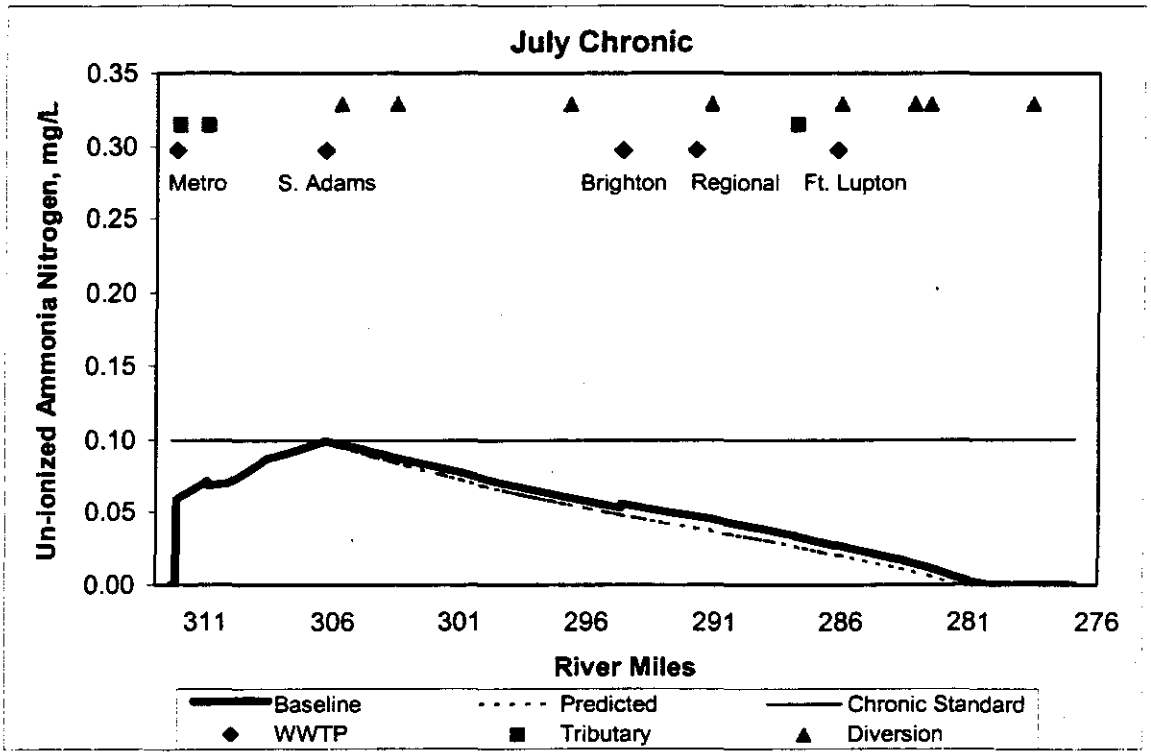
Table 44. Daily concentrations of nitrate in effluent from WWTPs in the Segment 15 Water Quality Model. Values for the proposed regional facility are set according to the Wastewater Utility Plan.

Model runs include all improvements incorporated in the recalibration of the Segment 15 model for purposes of estimating effluent characteristics of the Metro District, and also incorporate effluent characteristics of downstream dischargers. (4) Modelling is reported here for the Highway 85 site (mile 291.85).

For unionized ammonia, in all months of the year the critical point occurs well upstream in Segment 15 (between river mile 300 and 310). Proposed points of discharge for the Lower Regional South Platte Facility are downstream of the critical point and coincide with concentrations of unionized ammonia that are far below the acute and chronic standards for unionized ammonia in any month (Figure 15). The concentration of unionized ammonia would be slightly decreased over most of Segment 15 and Middle South Platte Segment 1 by operation of the Lower South Platte WWTP. This is explained by shifting of some effluent discharge from a moderately high ammonia source (the present dischargers) to a fully nitrified source (the Lower South Platte Regional Plant). Thus, no adverse effects are expected for operating the Lower South Platte Facility with respect to unionized ammonia at the proposed effluent limit of 5.0 mg/L.

Results for oxygen predictions are shown in Figure 16 and Table 42. The new version of the Segment 15 Water Quality Model extends beyond Segment 15 to Middle South Platte Segment 1, down to Road 28. Information on reaeration and hydrology is much weaker below Segment 15 than it is within Segment 15. Therefore, pending the collection of additional data on these two important variables, trend lines and graphs representing oxygen concentrations below Segment 15 are shown in gray scale, indicating that they are tentative. Relative effects can be modeled with much higher certainty, however, than absolute oxygen concentrations. Thus, the relative effect of the regional plant can be judged fairly accurately even with some uncertainty about absolute concentrations.

July is the critical month for oxygen in and below Segment 15 in that oxygen concentrations reach their lowest level with regard to the standard in this month. Modelling for year 2020 produces the most extreme results, but the differences between increments in development of the project are small. Also movement of the discharge point to the other two possible locations (Table 1) has trivial effects. It is likely to be below 0.5 mg/L. It is likely that the Metro District will propose to create a reaeration structure just above the Lupton Bottom diversion if further



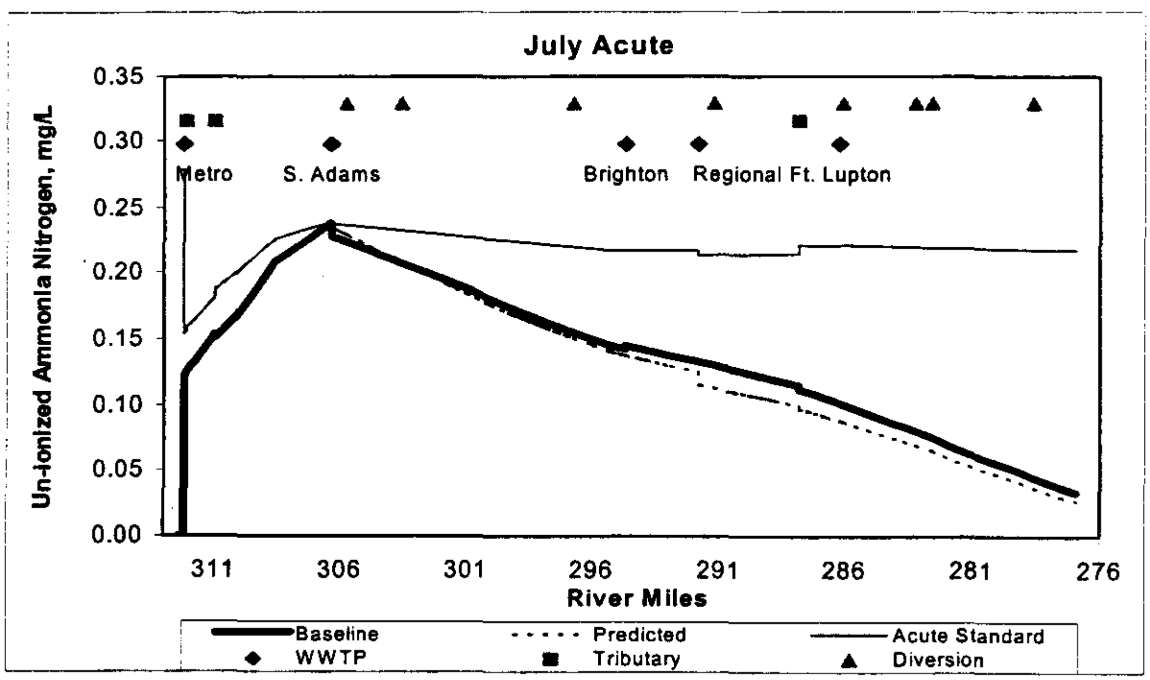
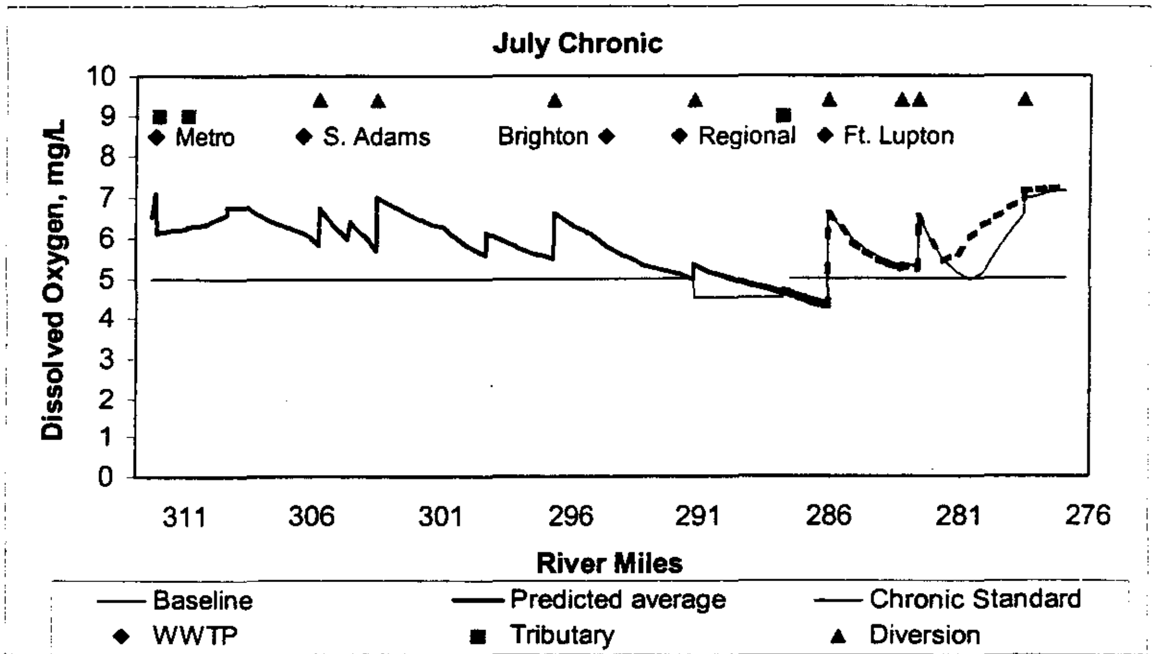


Figure 15. Ammonia predictions for July with (dashed) and without (black) the regional plant (year 2020).



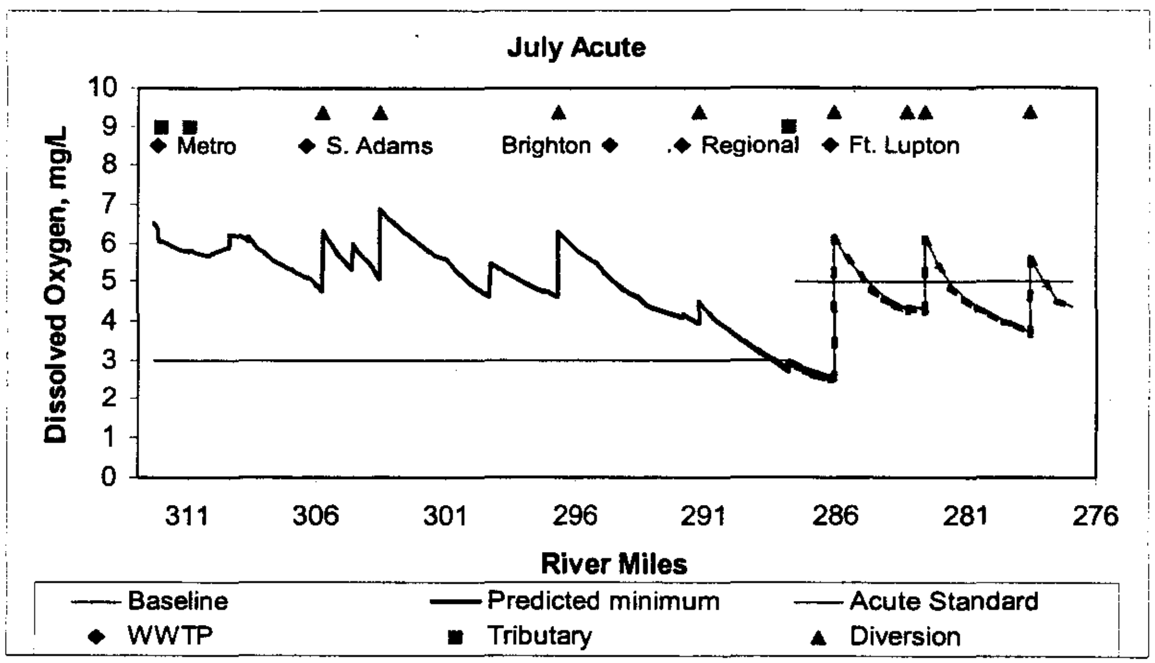
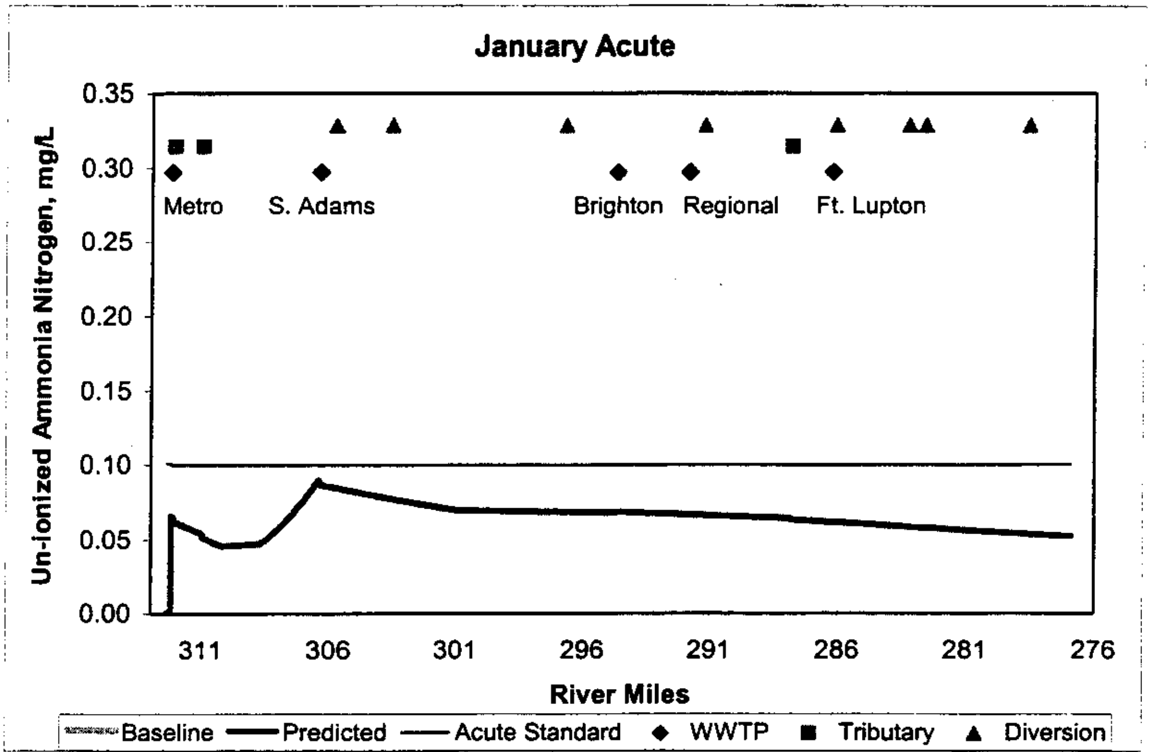


Figure 16. Oxygen predictions with (broad line) and without (thin line) the regional plant (year 2020).

studies continue to indicate insufficient oxygen near the bottom of Segment 15. A structure would offset the possibility of having the South Platte go slightly below the oxygen standard in the lower part of Segment 15 or Middle South Platte Segment 1. Any such measure would probably bring the oxygen concentrations sufficiently above the standard to render any incremental suppression of oxygen by the regional plant unimportant to compliance with the standard.

Appendix A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Metro
S. Adams
Brighton
Regional
Ft. Lupton
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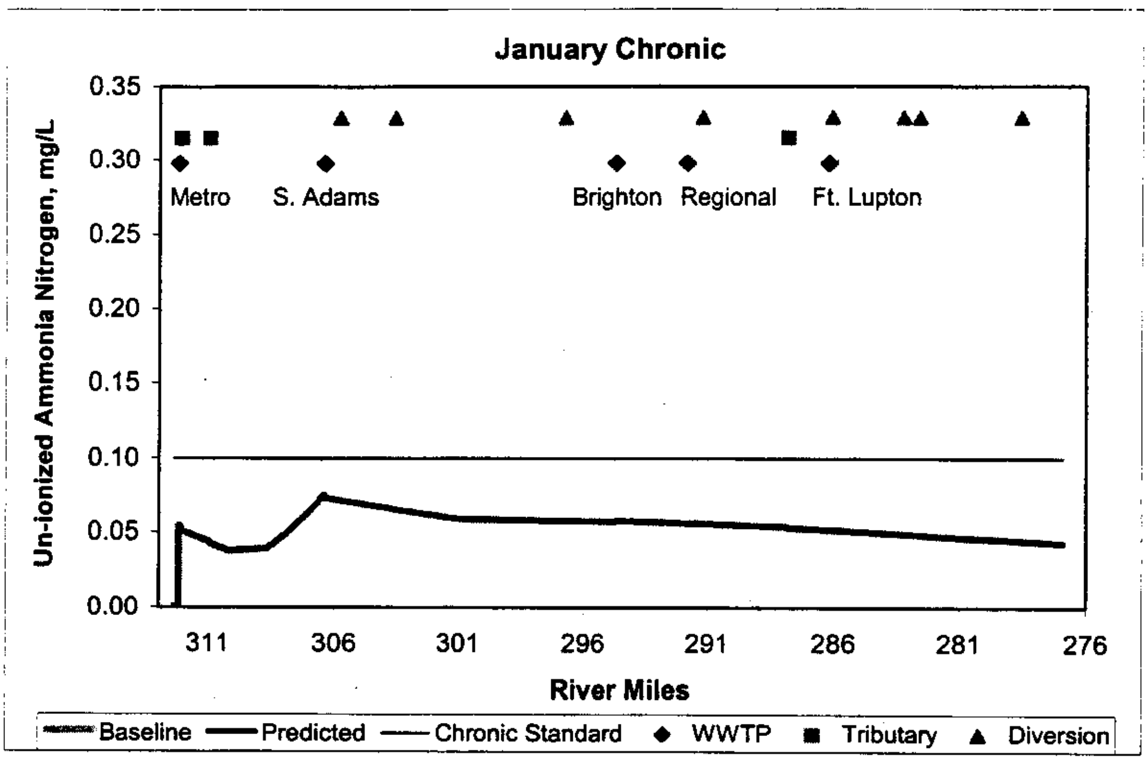
River Miles
Baseline
Predicted
Acute Standard
WWTP
Tributary
Diversion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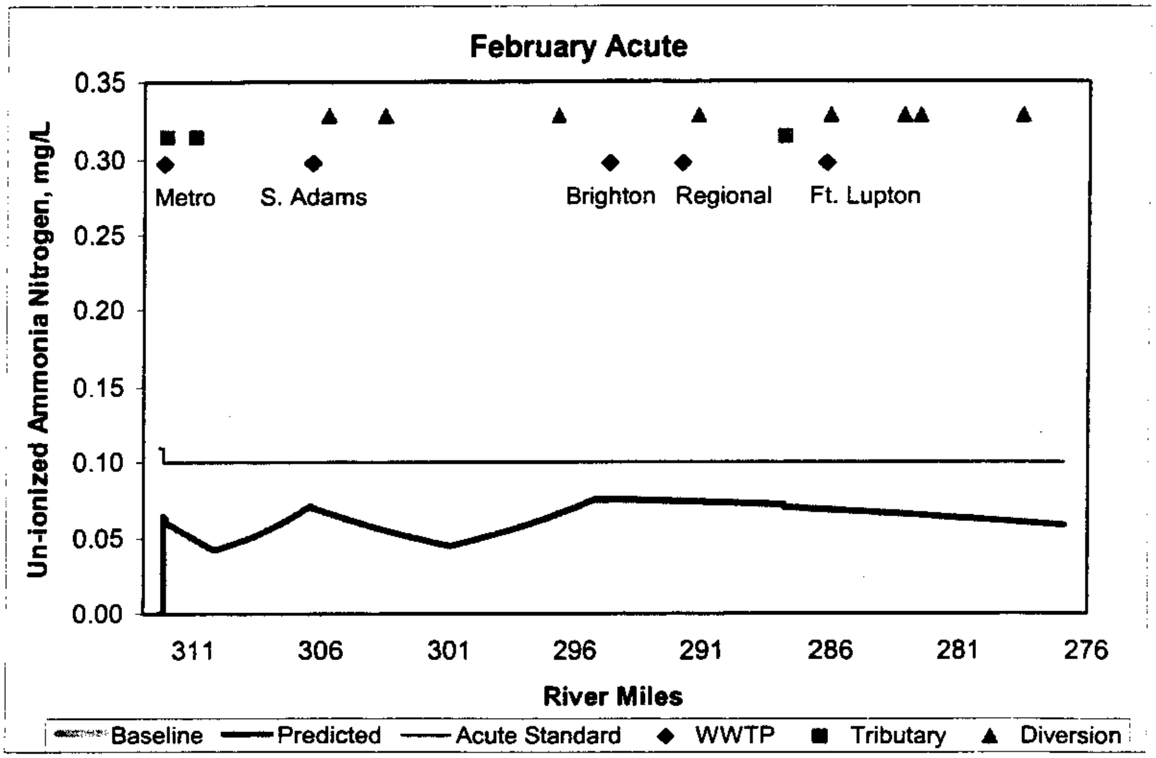
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Un-ionized Ammonia Nitrogen, mg/L
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Acute Standard
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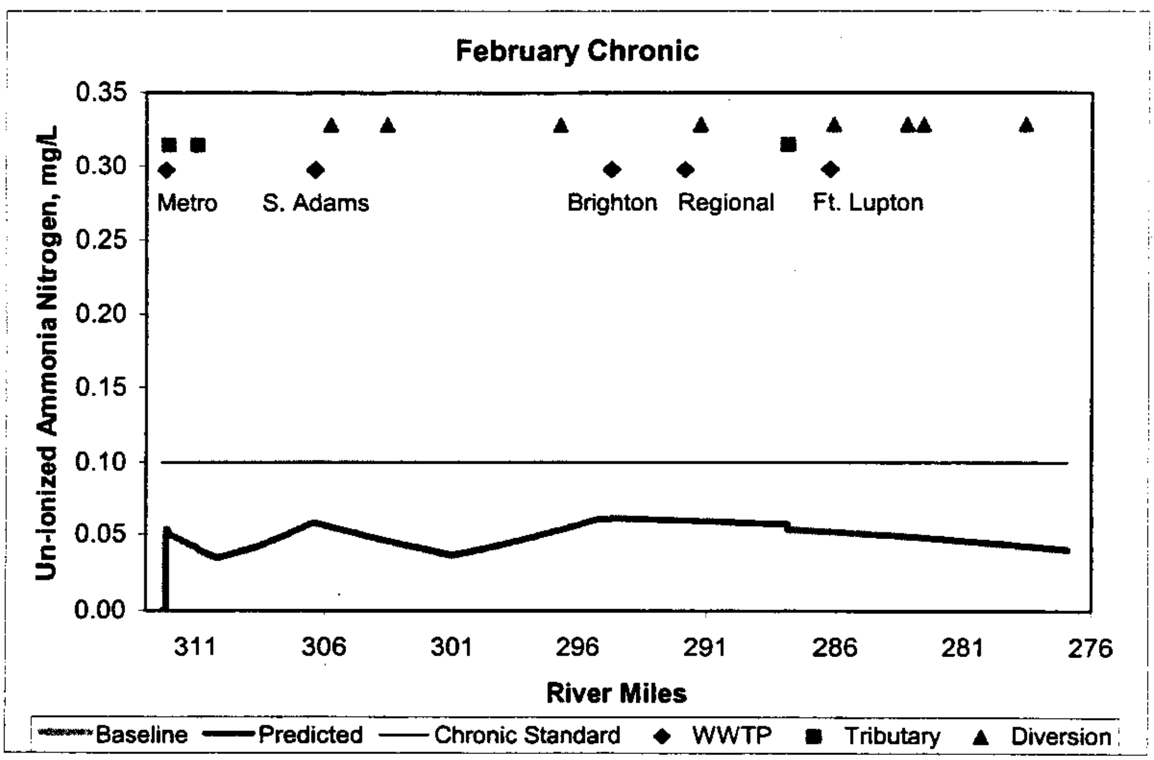
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Un-ionized Ammonia Nitrogen, mg/L
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River Miles
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Chronic Standard
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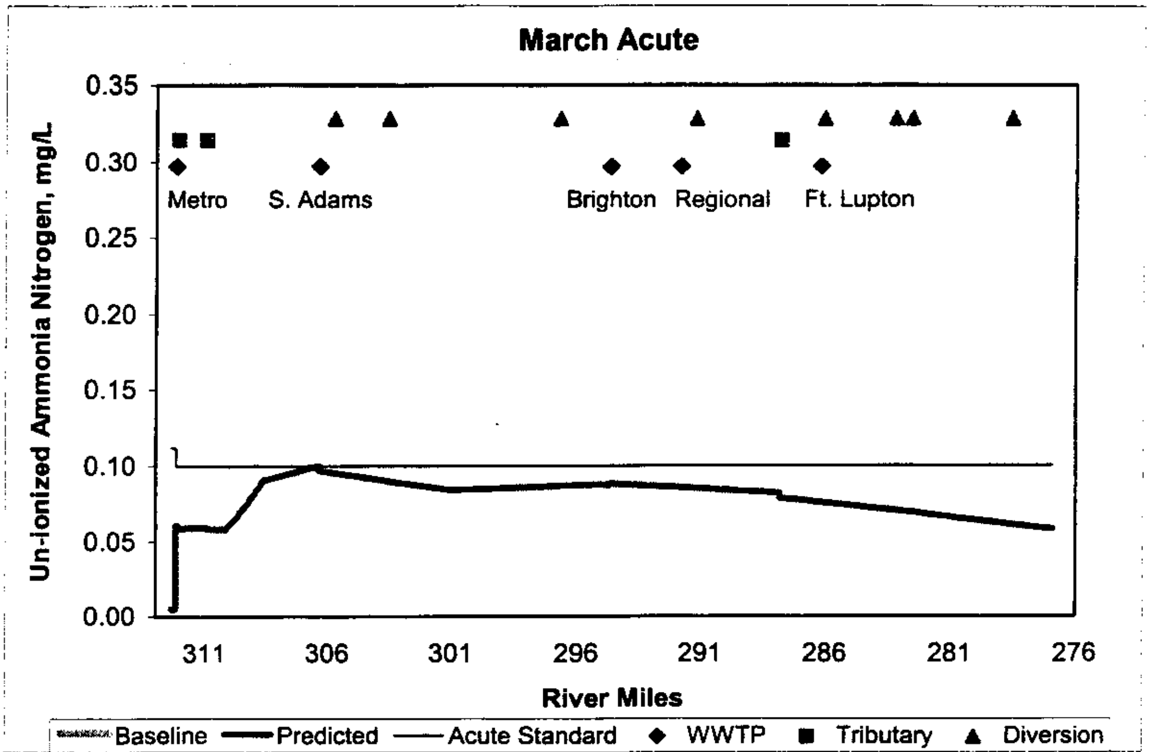
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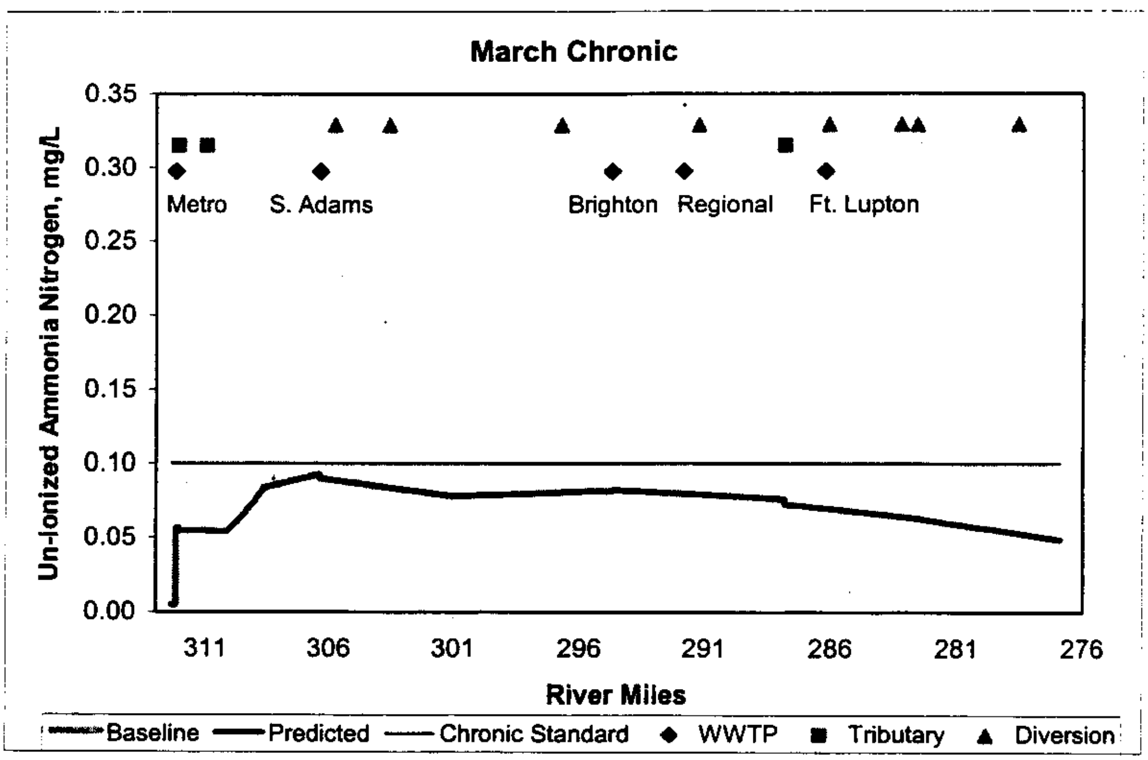
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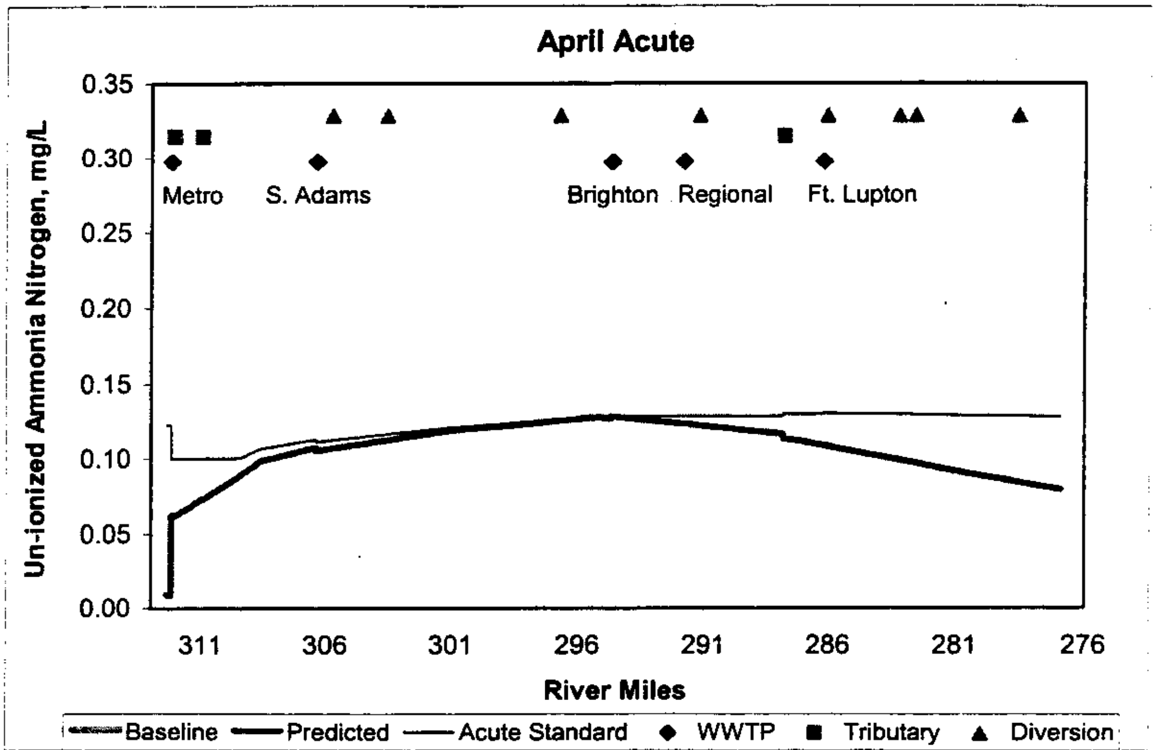
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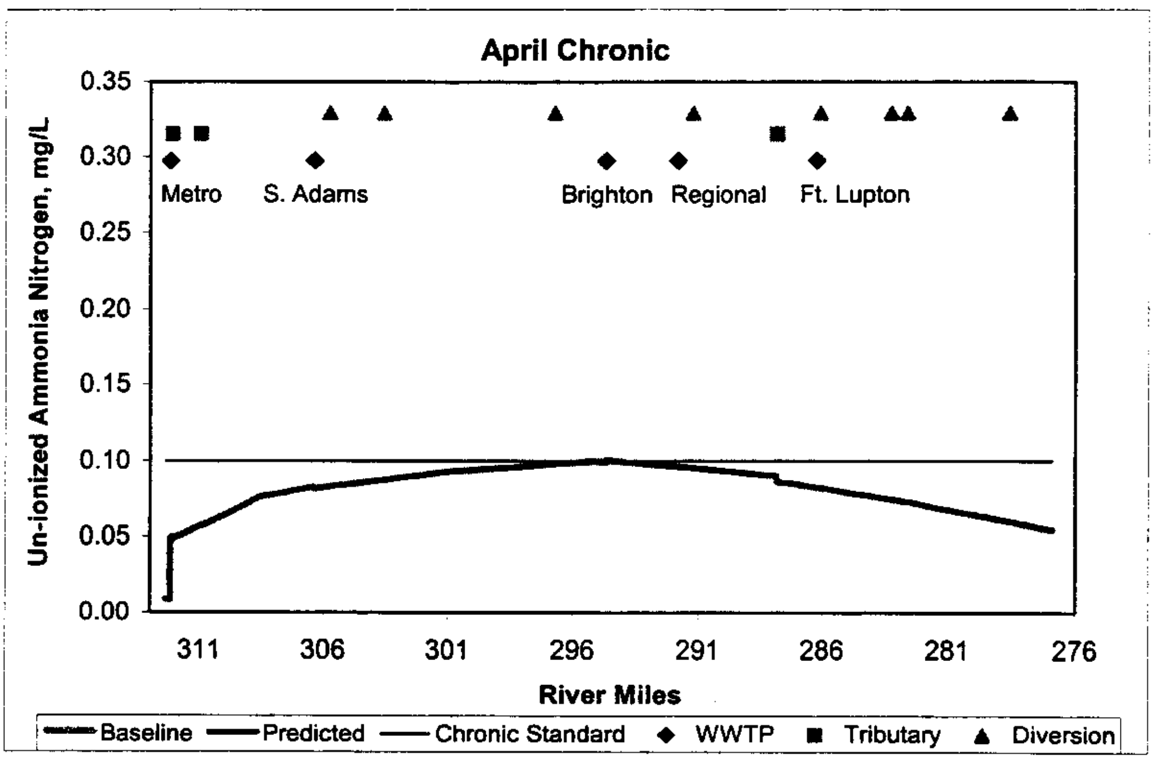
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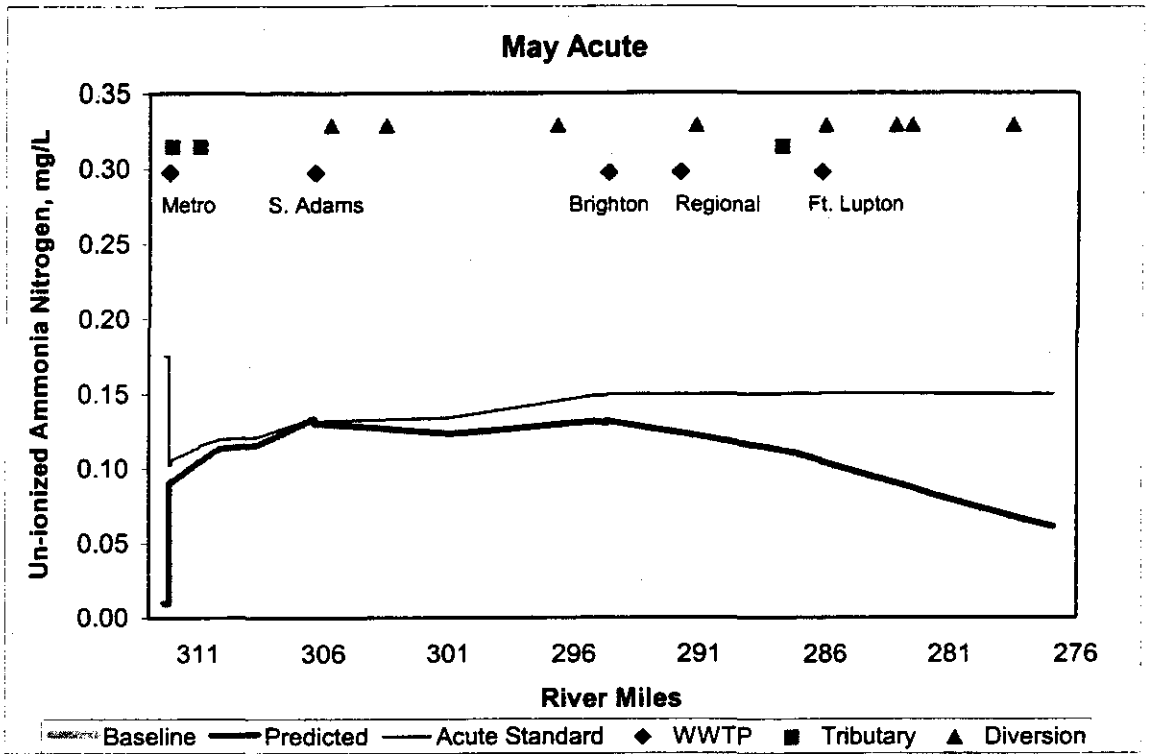
Diversion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Un-ionized Ammonia Nitrogen, mg/L
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Acute Standard
WWTP
Tributary
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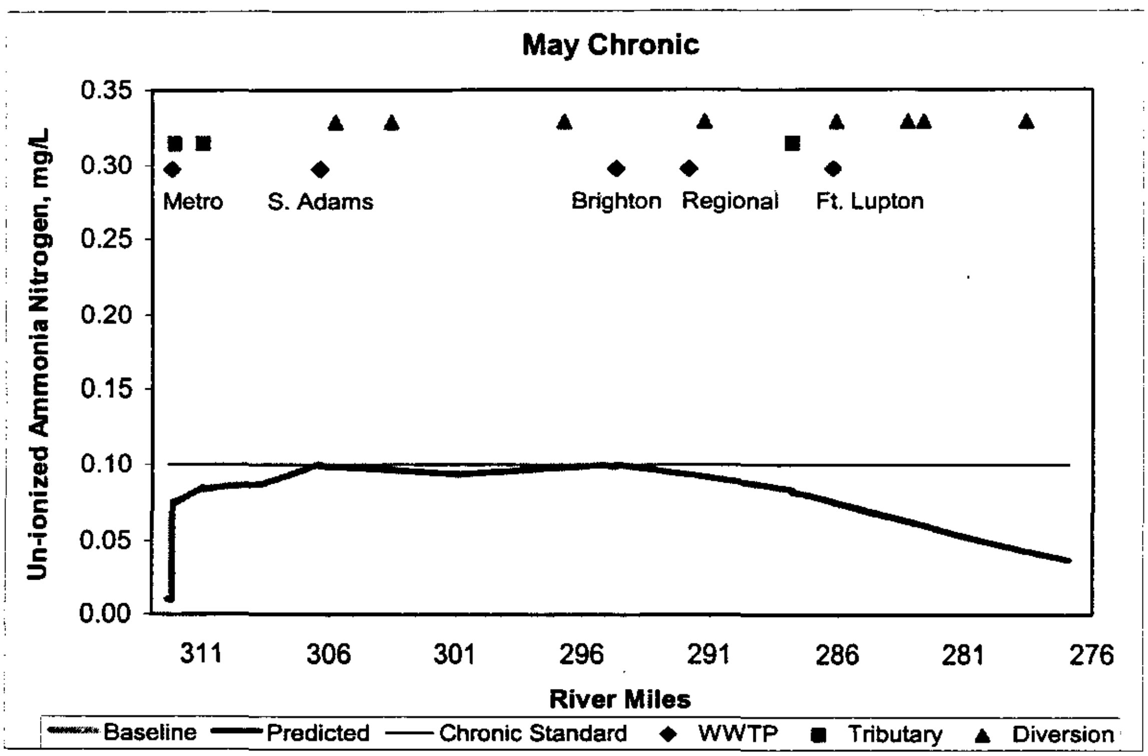
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Un-ionized Ammonia Nitrogen, mg/L
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Chronic Standard
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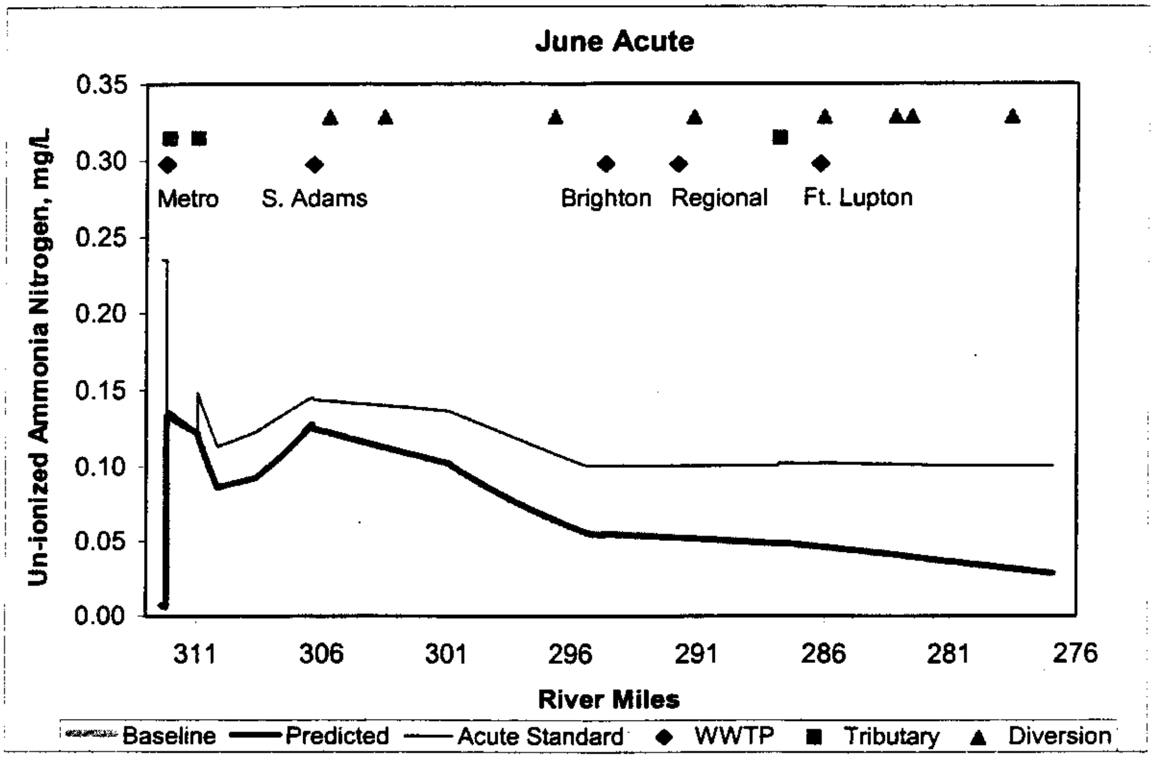
Tributary
Diversion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Metro
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Brighton
Regional
Ft. Lupton
Un-ionized Ammonia Nitrogen, mg/L
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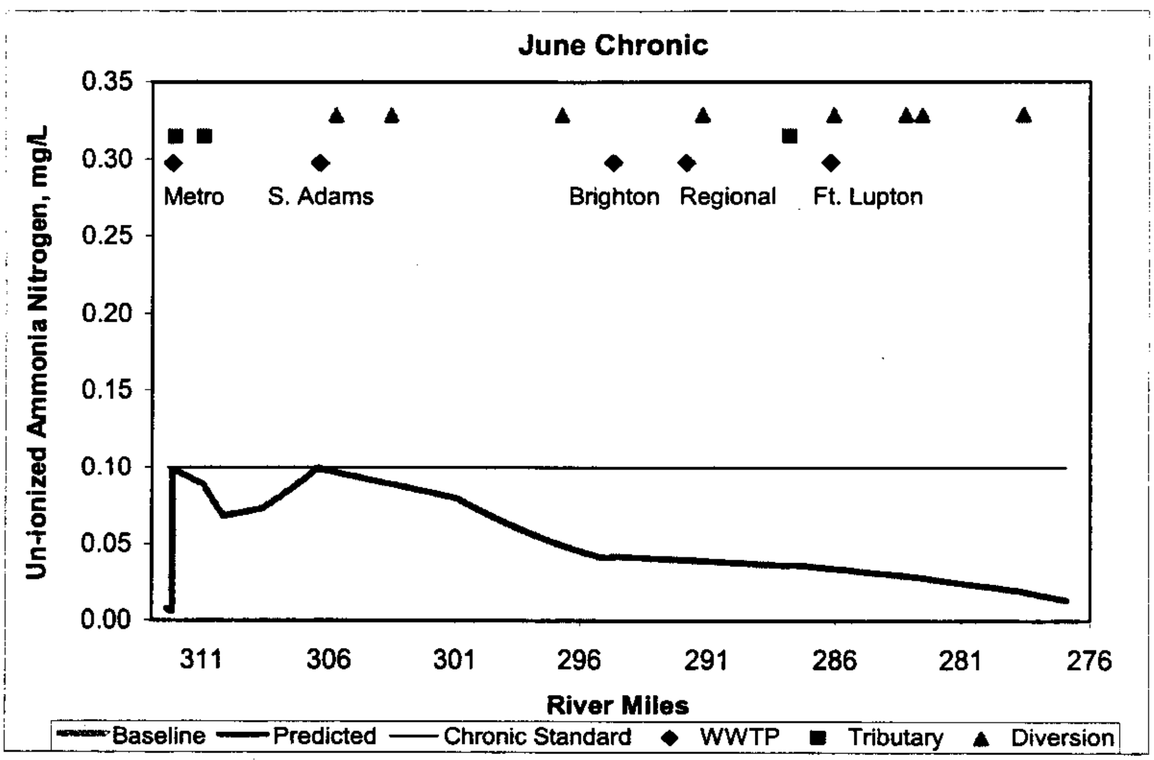
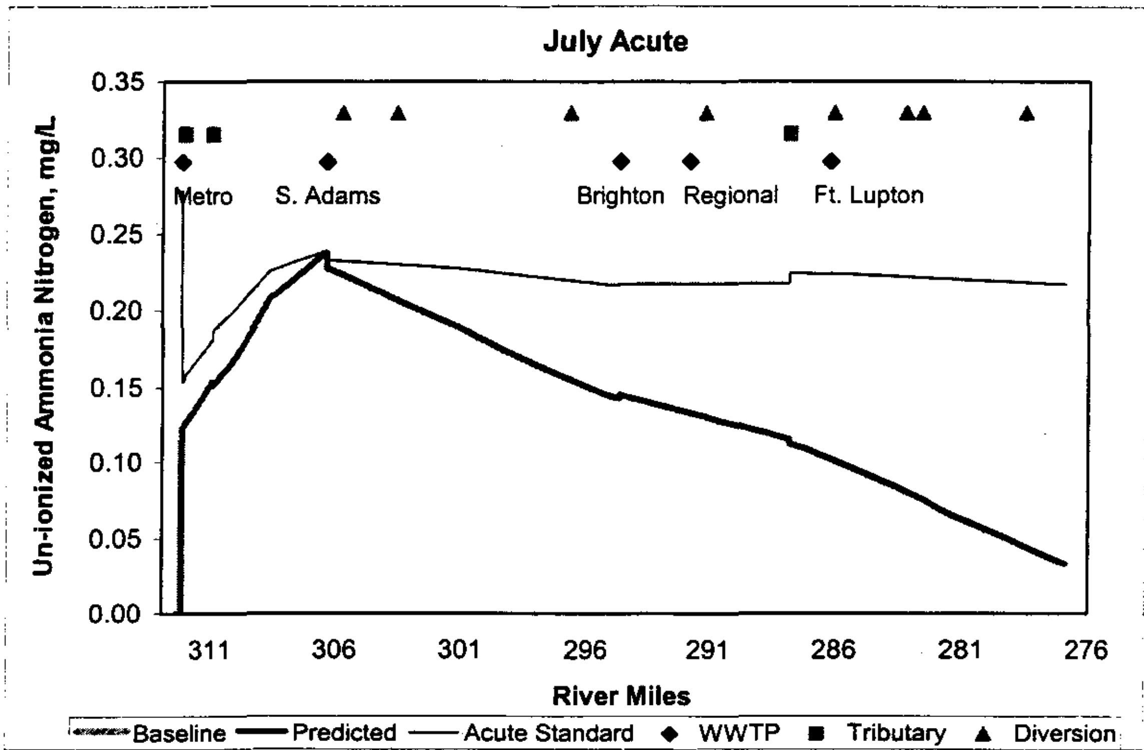
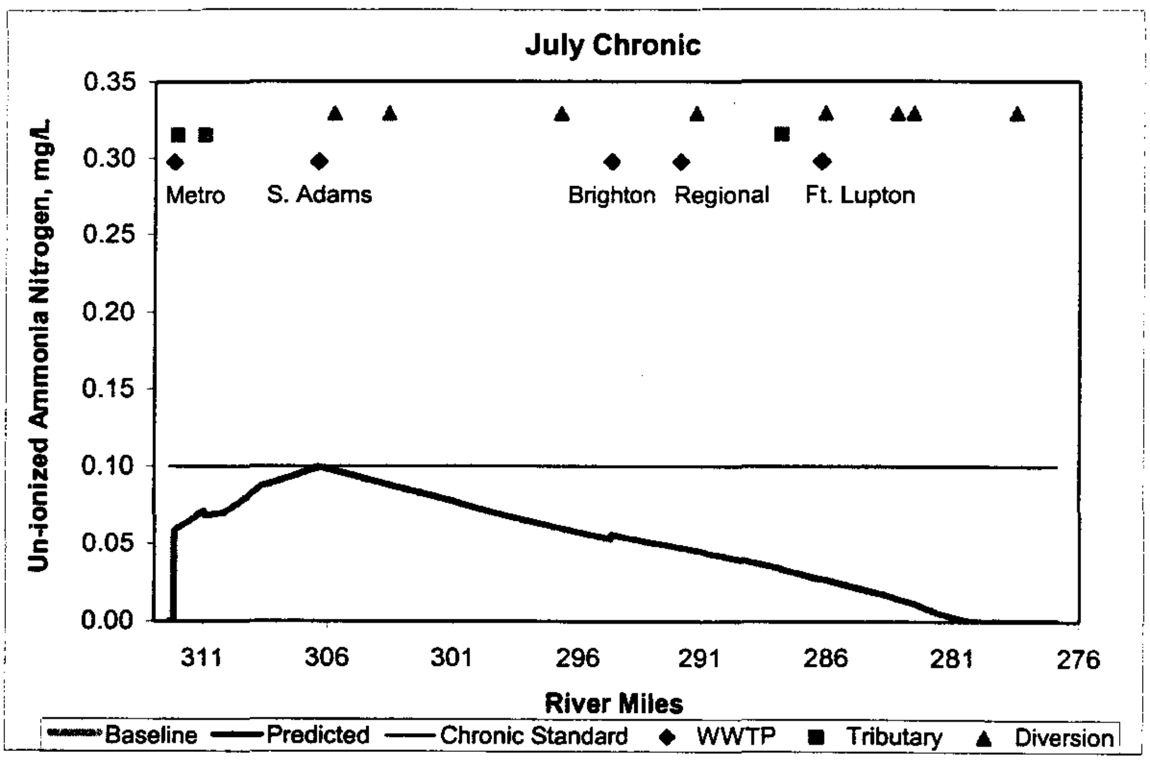
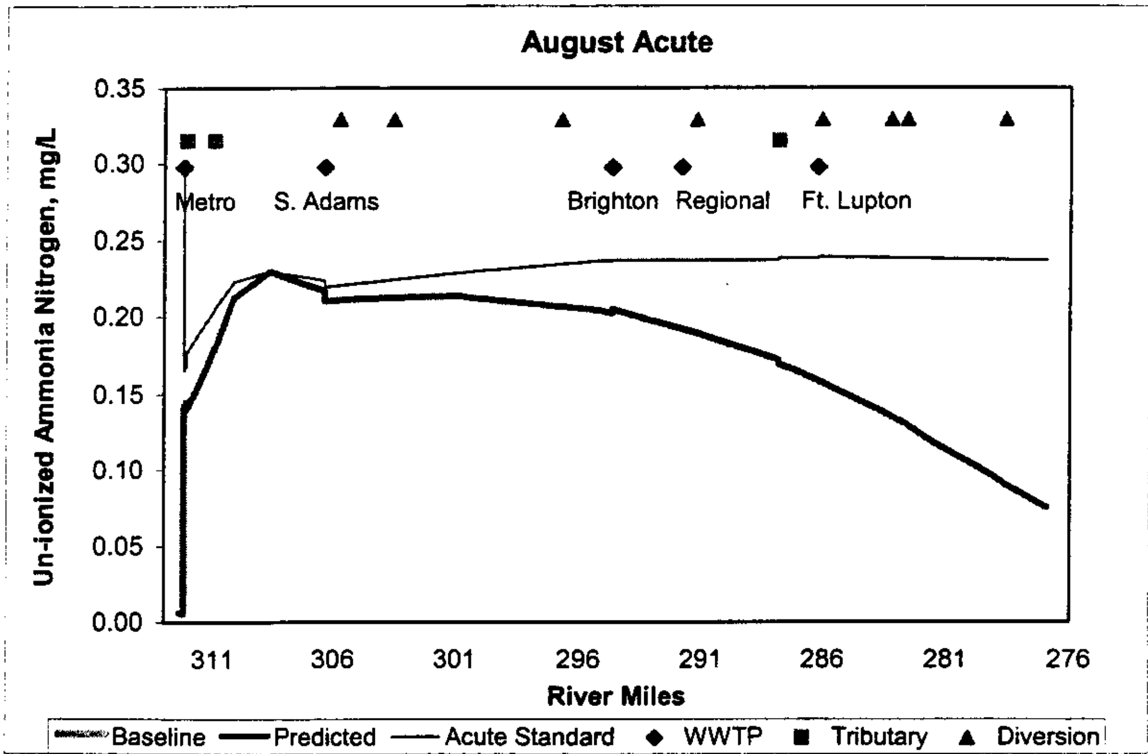
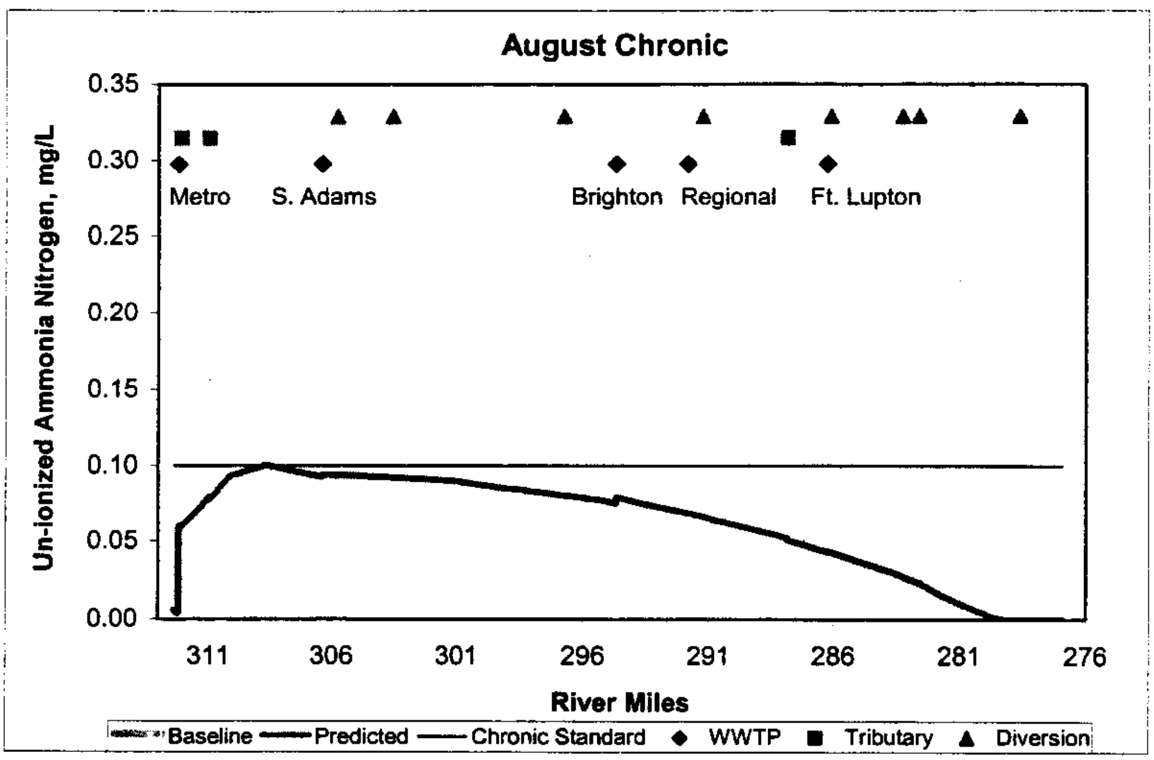
Diversion

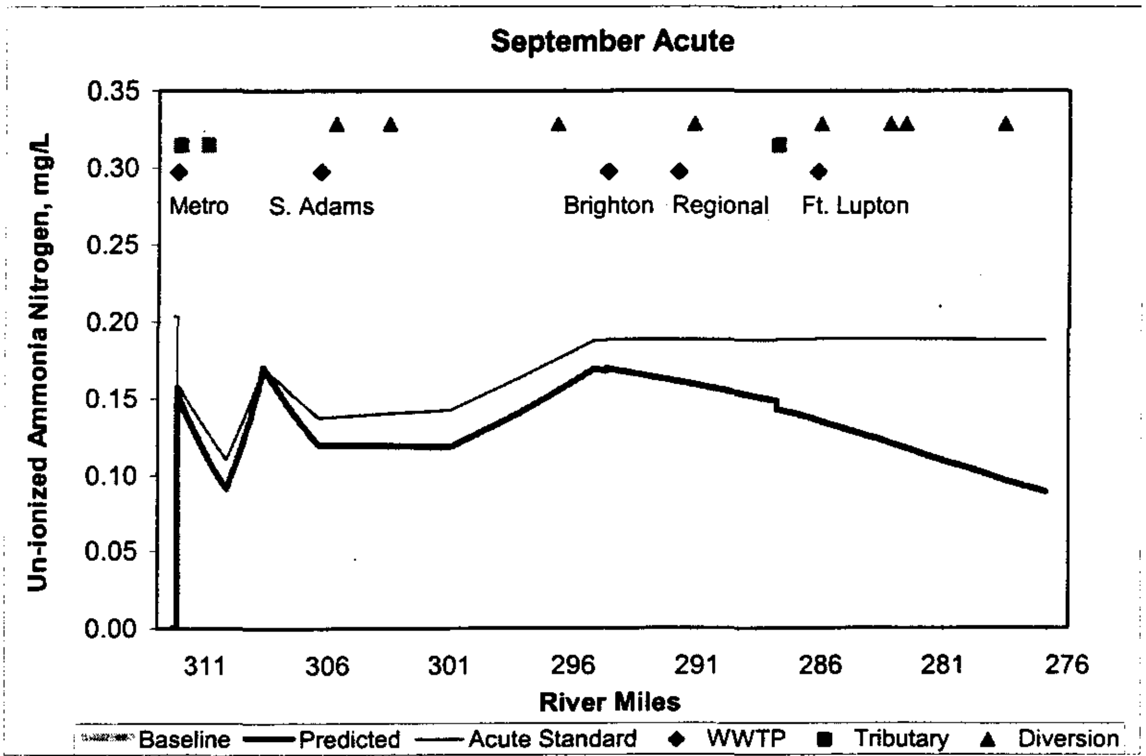

June Chronic
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Metro
S. Adams
Brighton
Regional
Ft. Lupton
Un-ionized Ammonia Nitrogen, mg/L
311
306
301
296
291
286
281
276
River Miles
Baseline
Predicted
Chronic Standard
WWTP
Tributary
Diversion


July Acute
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Un-ionized Ammonia Nitrogen, mg/L
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
296
291
286
281
276
River Miles
Baseline
Predicted
Acute Standard
WWTP
Tributary
Diversion

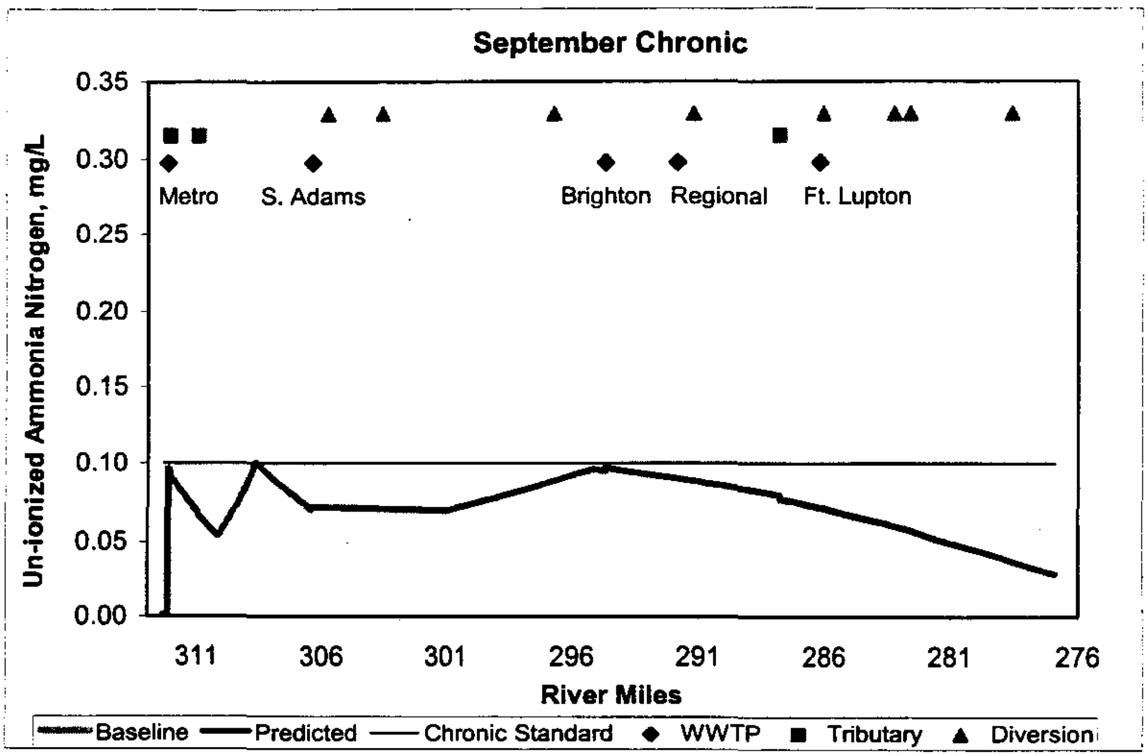

July Chronic
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Un-ionized Ammonia Nitrogen, mg/L
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
296
291
286
281
276
River Miles
Baseline
Predicted
Chronic Standard
WWTP
Tributary
Diversion


August Acute
Un-ionized Ammonia Nitrogen, mg/L
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
296
291
286
281
276
River Miles
Baseline
Predicted
Acute Standard
WWTP
Tributary
Diversion


August Chronic
Un-ionized Ammonia Nitrogen, mg/L
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
296
291
286
281
276
River Miles
Baseline
Predicted
Chronic Standard
WWTP
Tributary
Diversion



September Acute
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Un-ionized Ammonia Nitrogen, mg/L
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
296
291
286
281
276
River Miles
Baseline
Predicted
Acute Standard
WWTP
Tributary
Diversion



September Chronic
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Un-ionized Ammonia Nitrogen, mg/L
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
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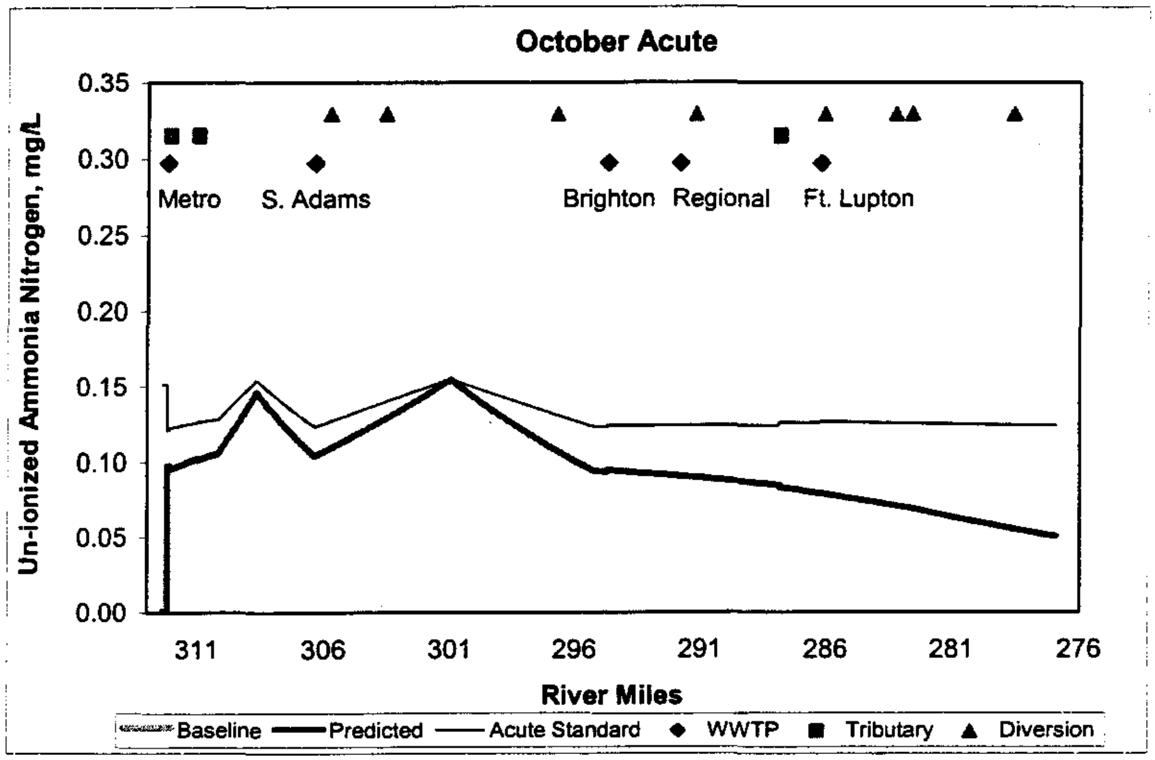
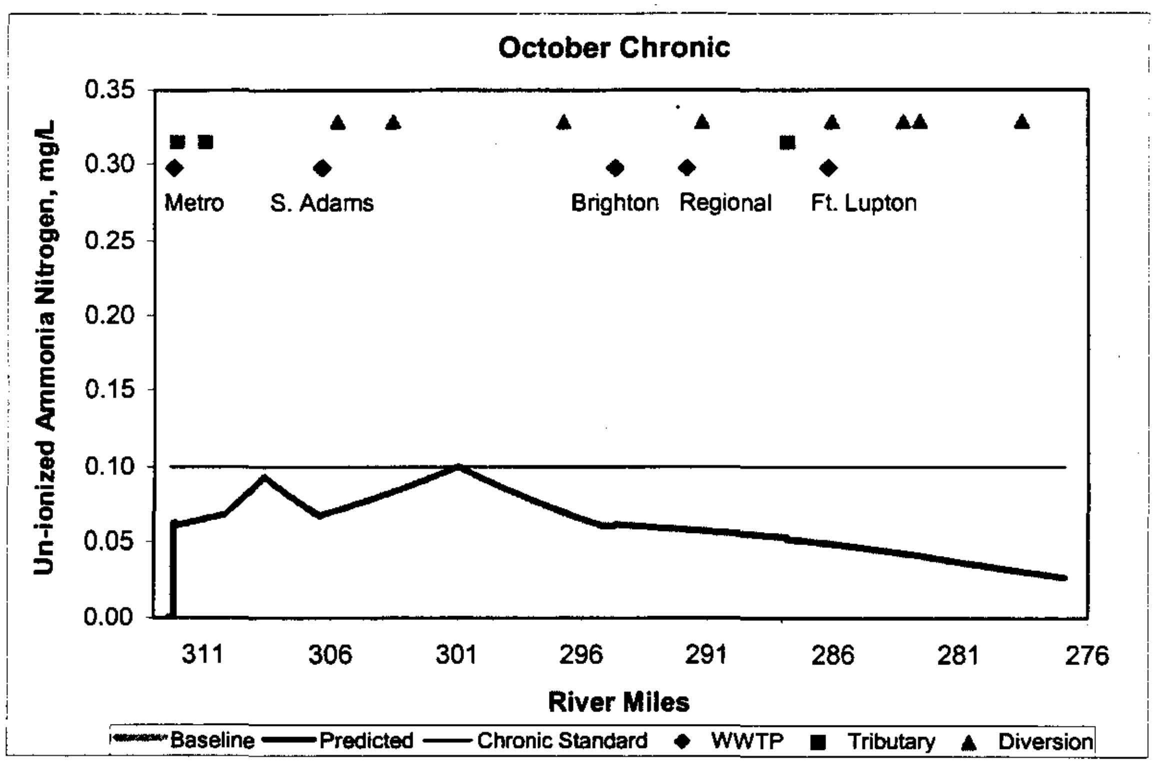
291
286
281
276
River Miles
Baseline
Predicted
Chronic Standard
WWTP
Tributary
Diversion


October Acute
Un-ionized Ammonia Nitrogen, mg/L
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
296
291
286
281
276
River Miles
Baseline
Predicted
Acute Standard
WWTP
Tributary
Diversion


October Chronic
Un-ionized Ammonia Nitrogen, mg/L
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Metro
S. Adams
Brighton
Regional
Ft. Lupton
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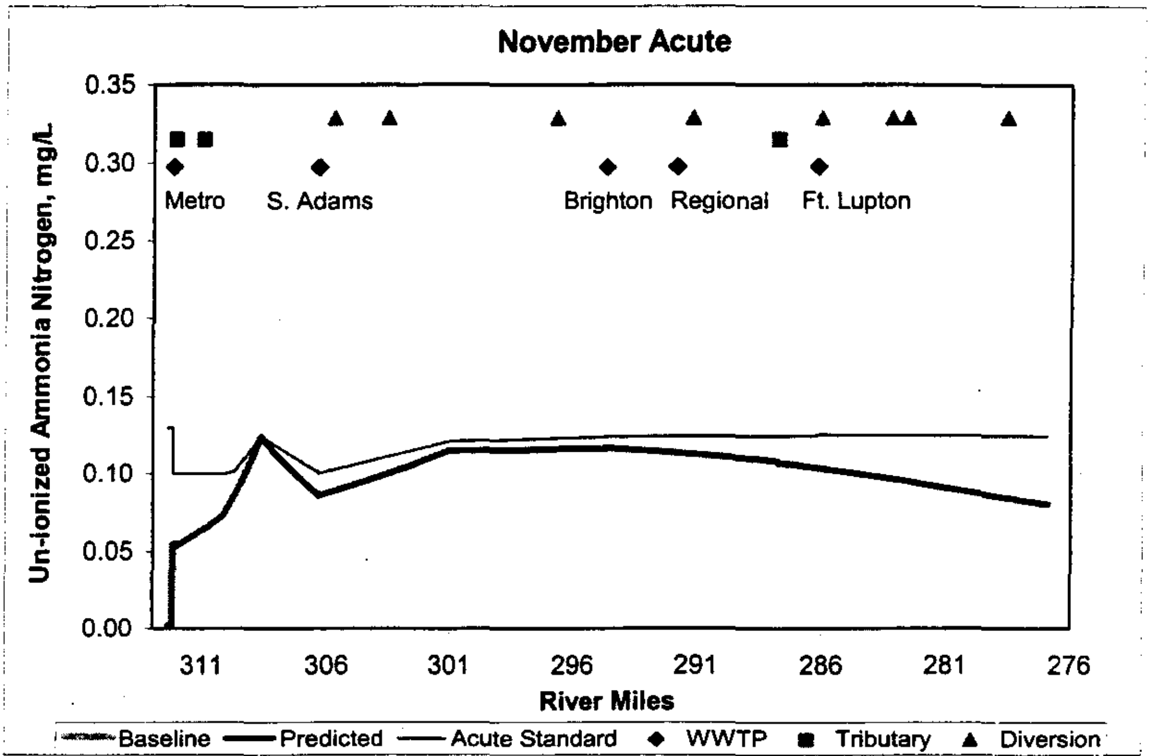
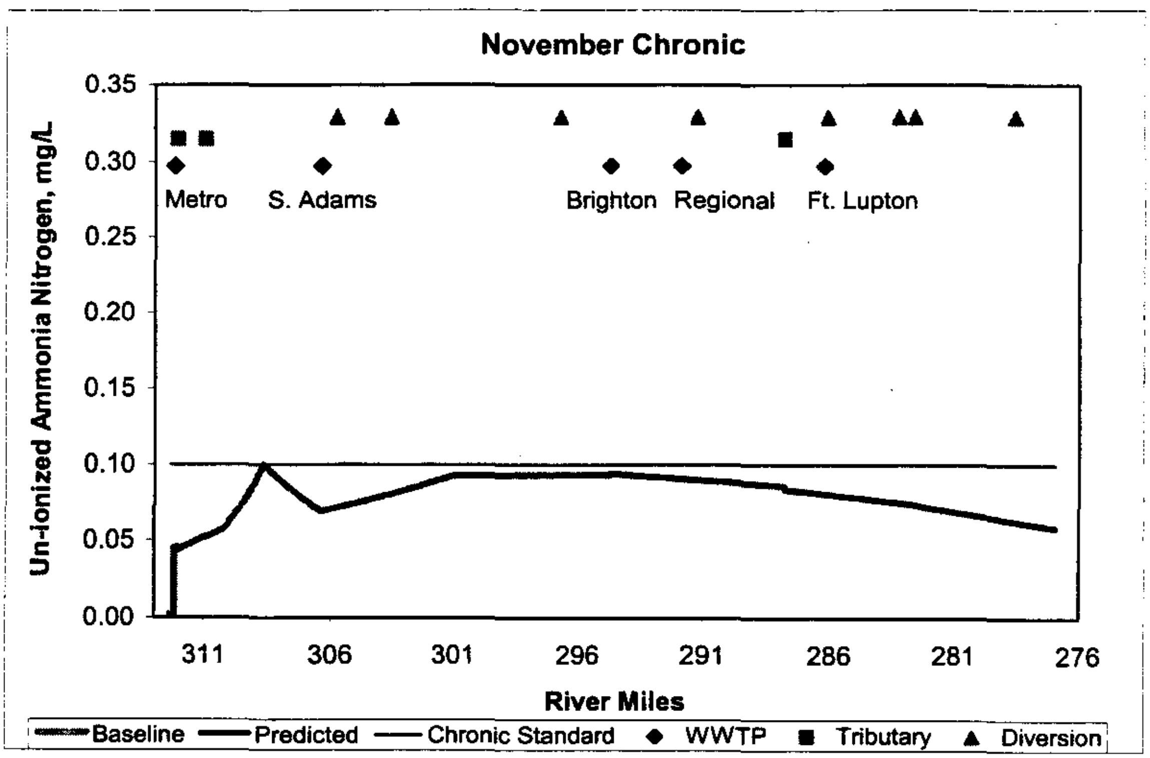
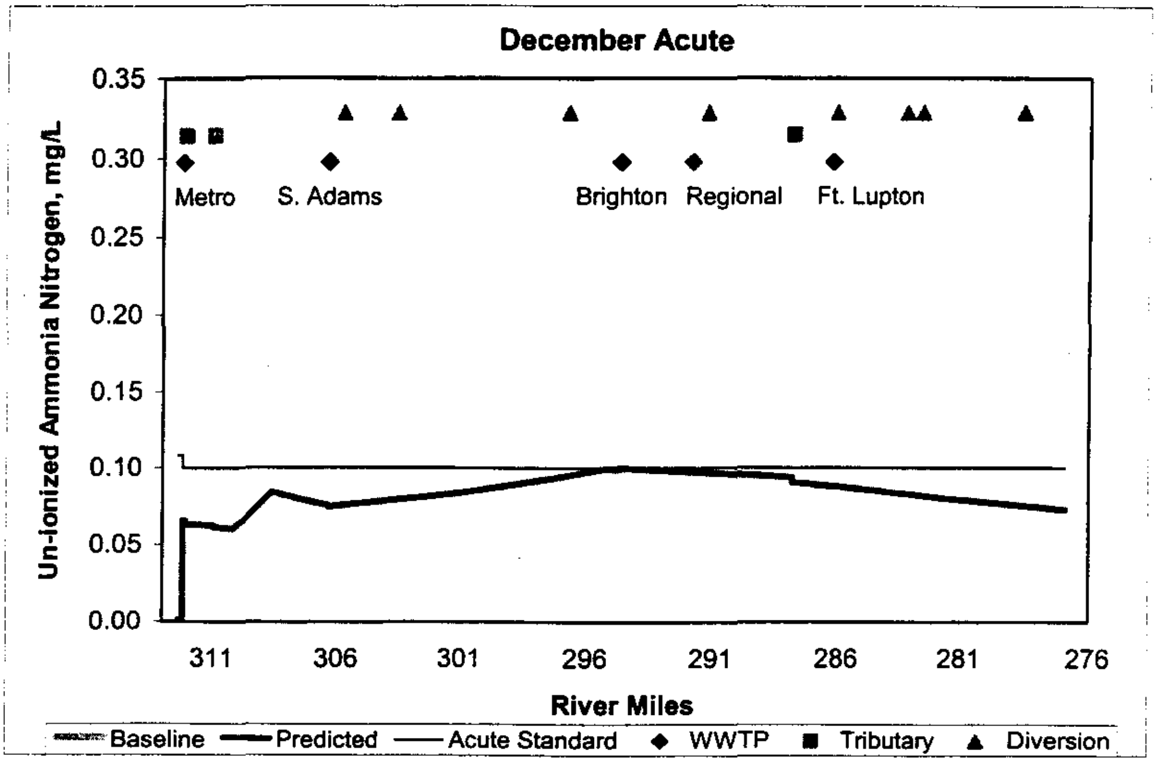
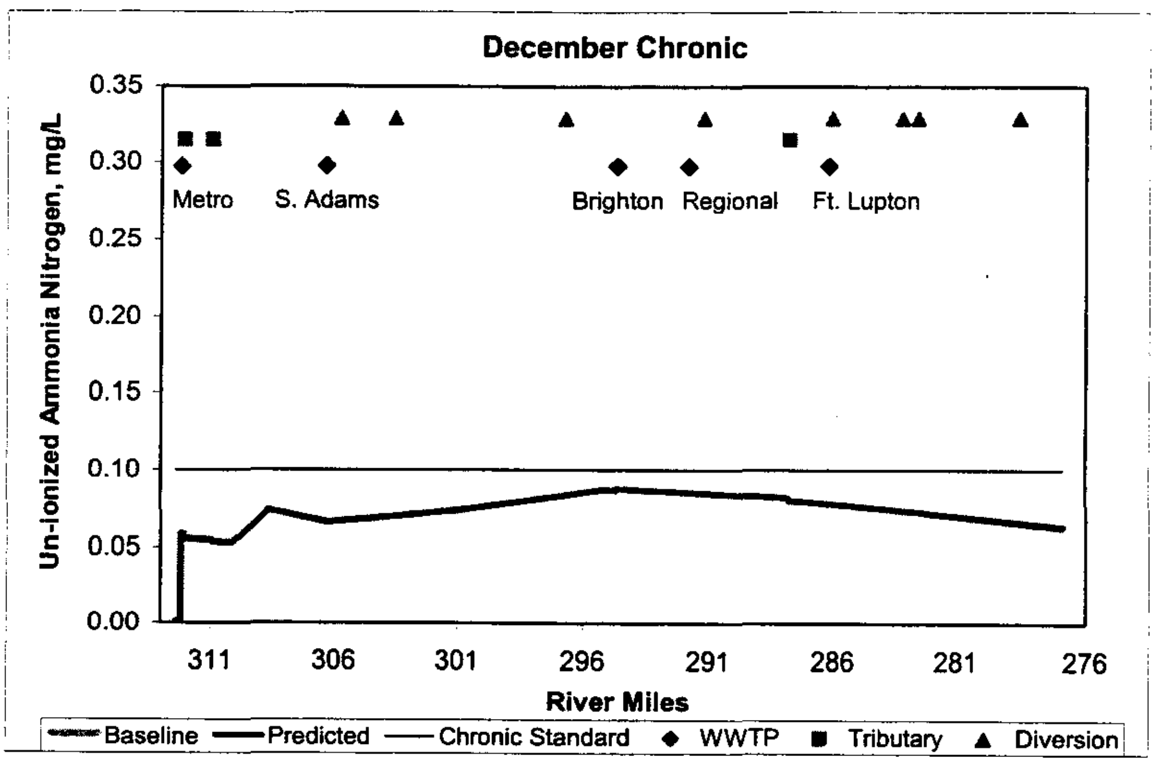
286
281
276
River Miles
Baseline
Predicted
Chronic Standard
WWTP
Tributary
Diversion


November Acute
Un-ionized Ammonia Nitrogen, mg/L
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
296
291
286
281
276
River Miles
Baseline
Predicted
Acute Standard
WWTP
Tributary
Diversion


November Chronic
Un-ionized Ammonia Nitrogen, mg/L
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
296
291
286
281
276
River Miles
Baseline
Predicted
Chronic Standard
WWTP
Tributary
Diversion

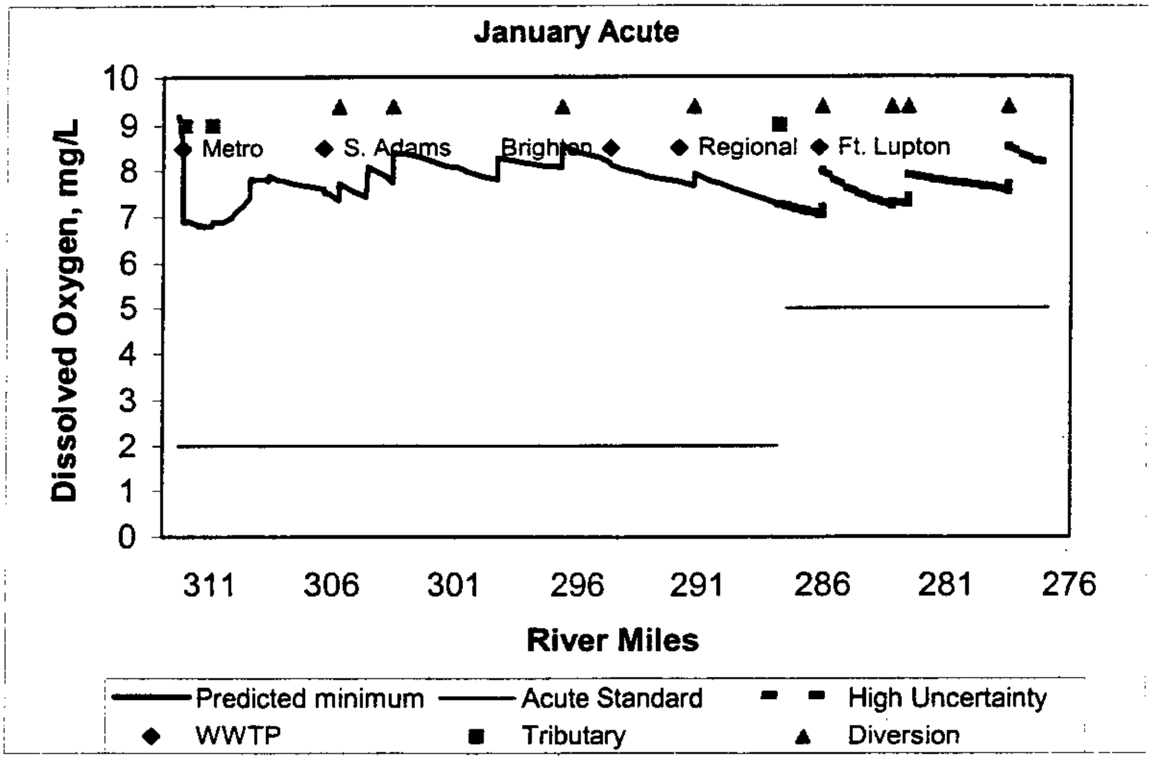


December Acute
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Un-Ionized Ammonia Nitrogen, mg/L
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
296
291
286
281
276
River Miles
Baseline
Predicted
Acute Standard
WWTP
Tributary
Diversion

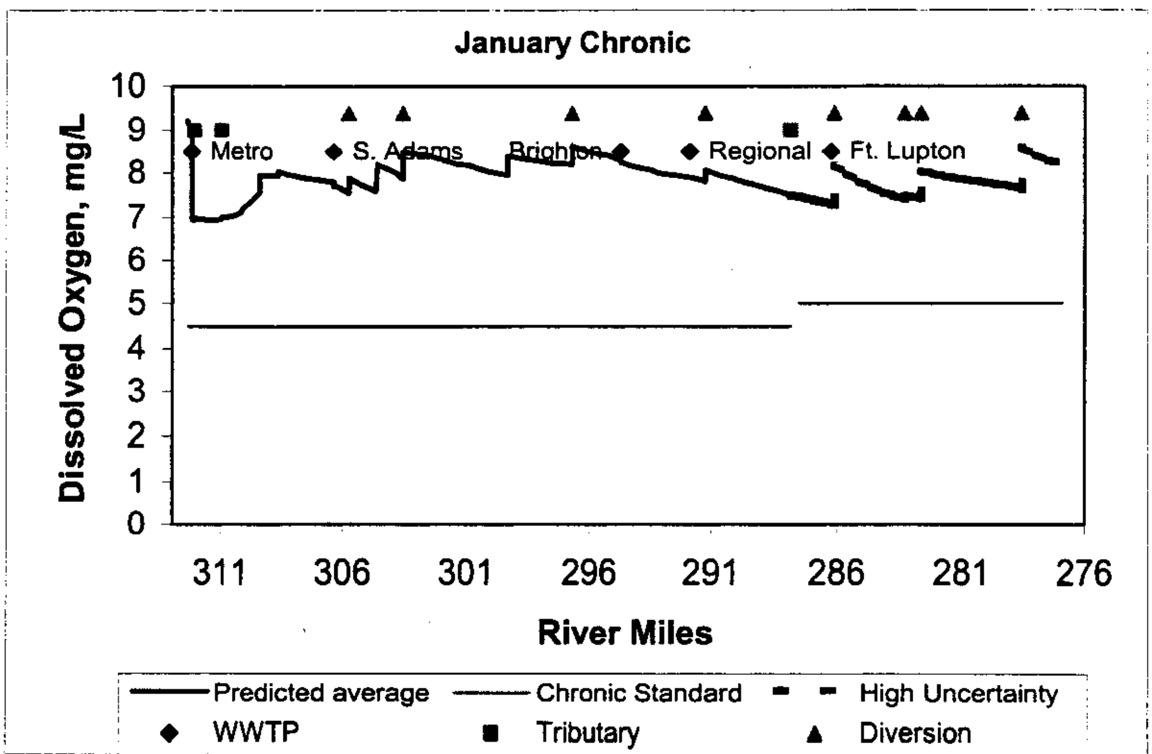


December Chronic
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Un-Ionized Ammonia Nitrogen, mg/L
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
296
291
286
281
276
River Miles
Baseline
Predicted
Chronic Standard
WWTP
Tributary
Diversion

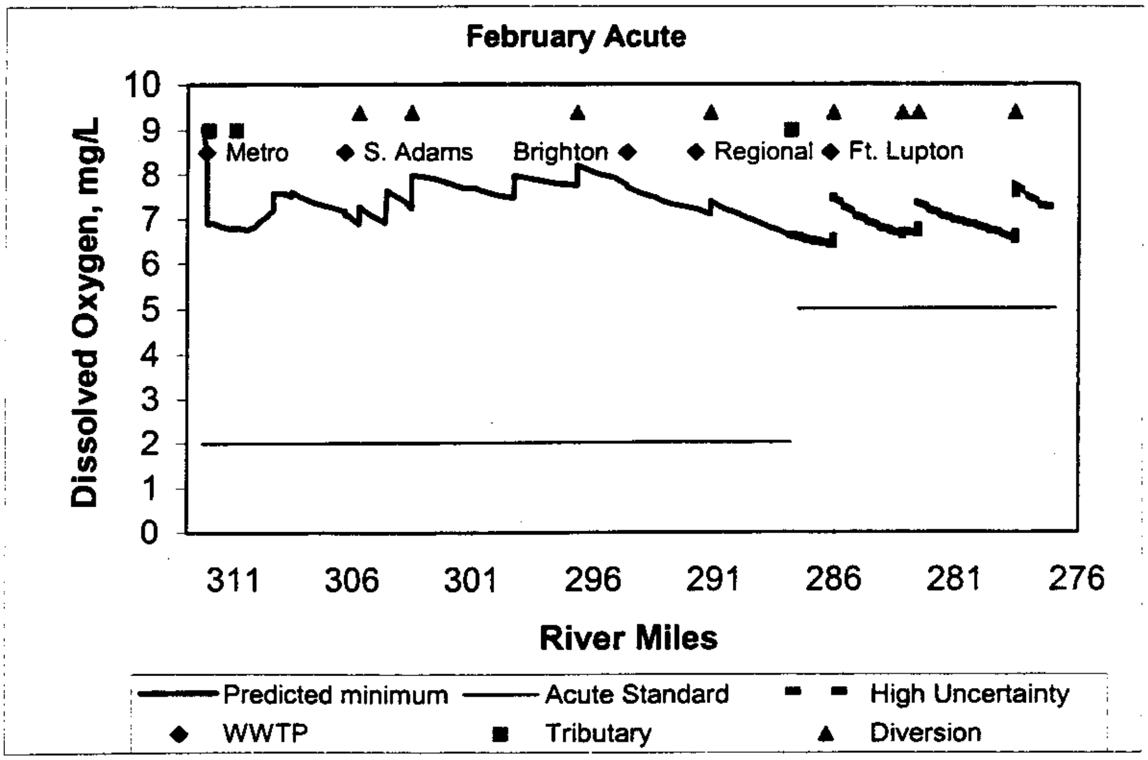
Appendix B

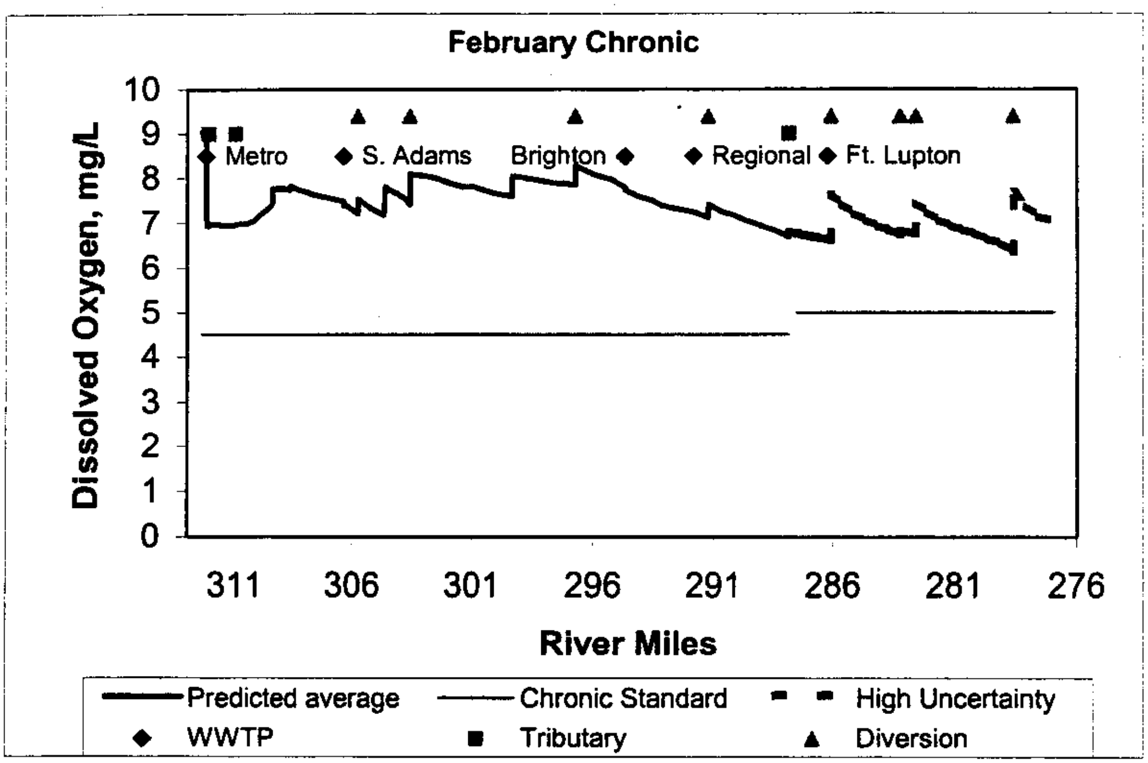


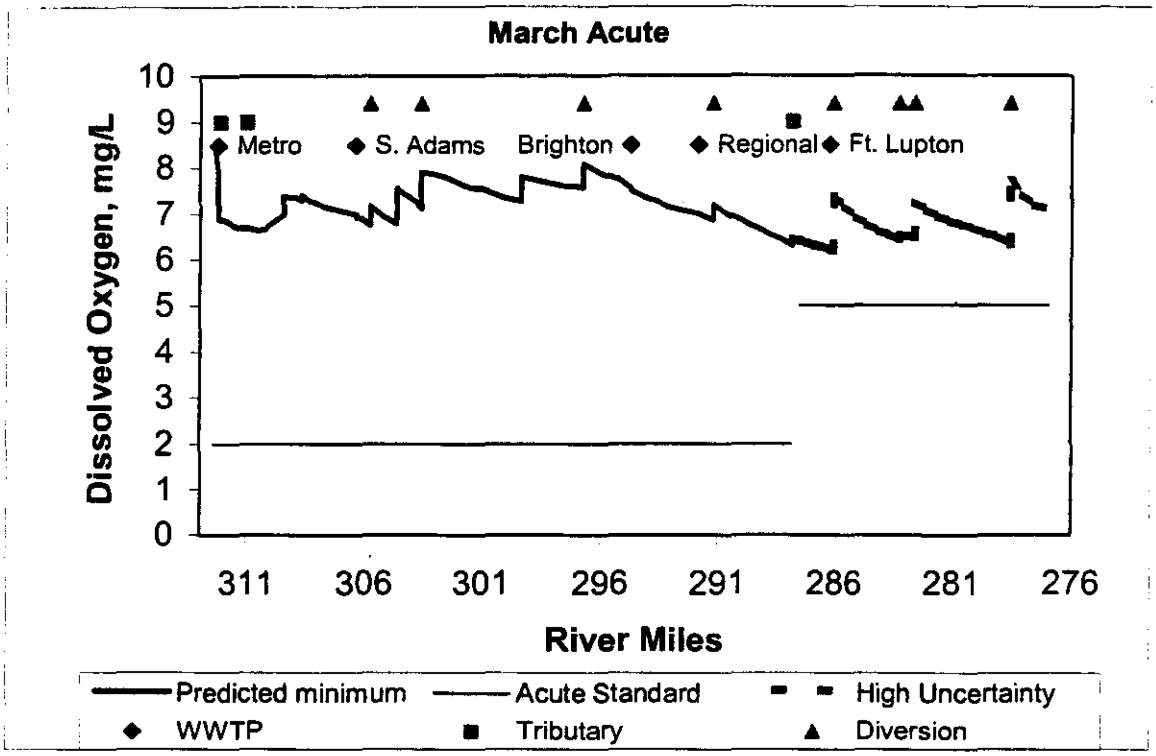
January Acute
Dissolved Oxygen, mg/L
10
9
8
7
6
5
4
3
2
1
0
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
296
291
286
281
276
River Miles
Predicted minimum
Acute Standard
High Uncertainty
WWTP
Tributary
Diversion

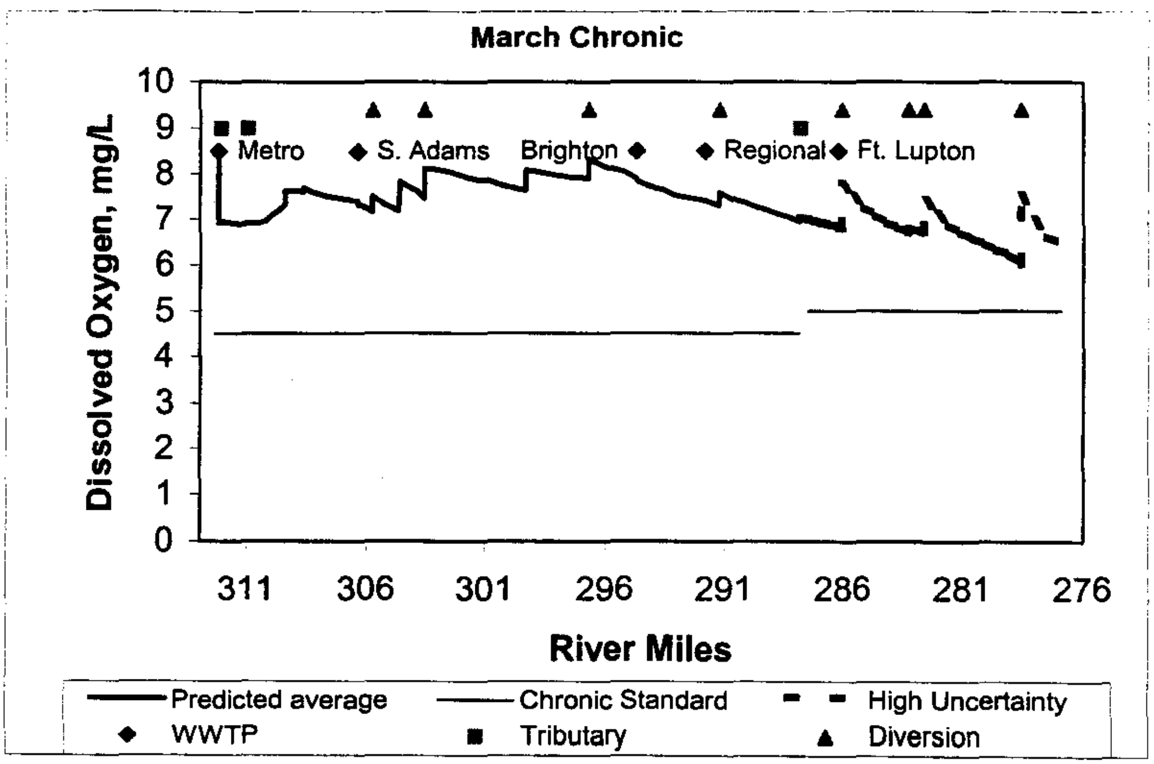


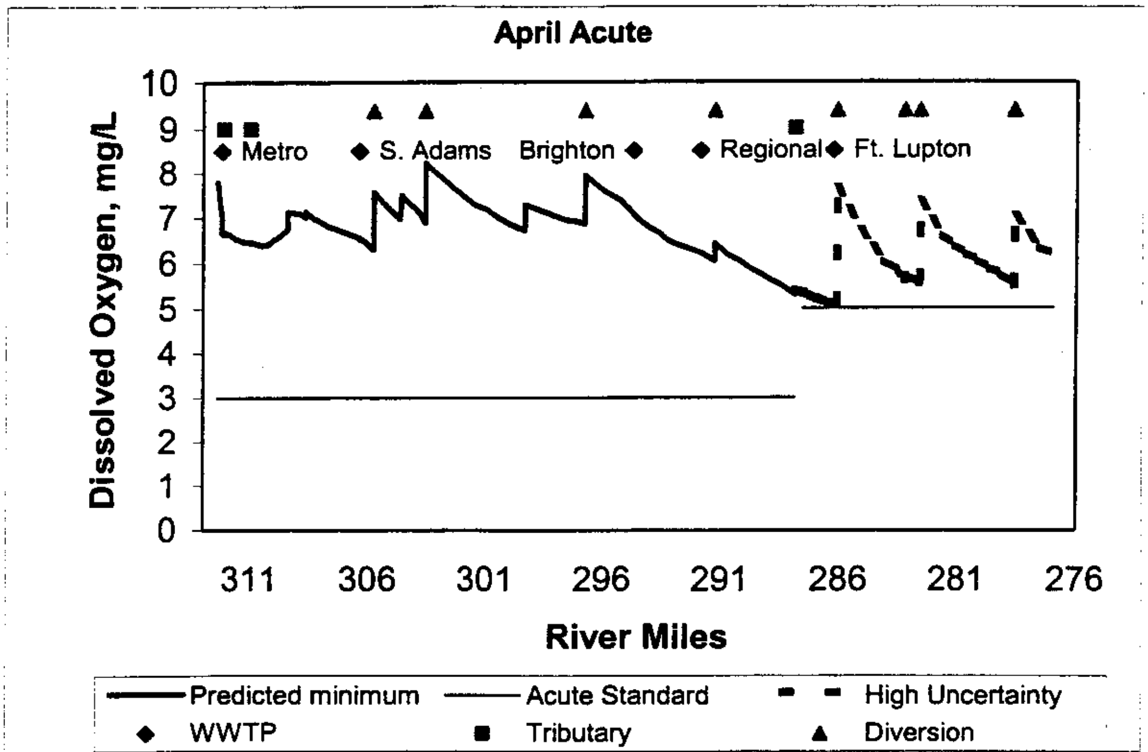
January Chronic
Dissolved Oxygen, mg/L
10
9
8
7
6
5
4
3
2
1
0
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
296
291
286
281
276
River Miles
Predicted average
Chronic Standard
High Uncertainty
WWTP
Tributary
Diversion

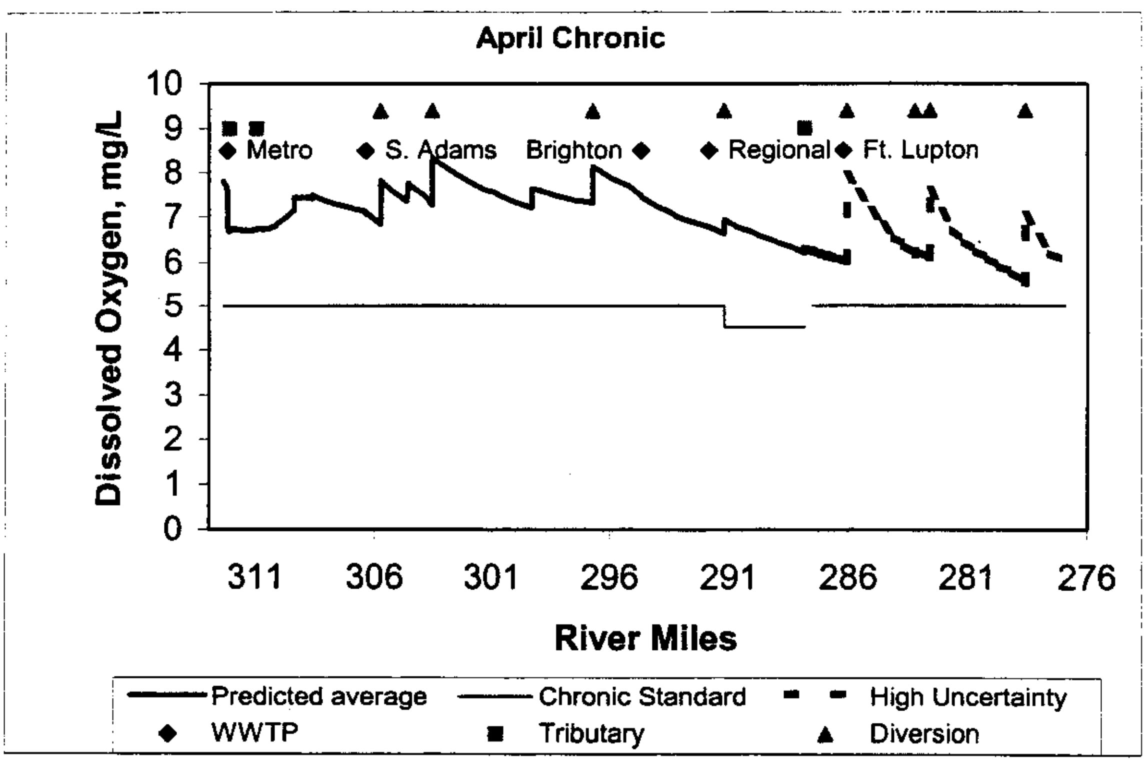

February Acute
Dissolved Oxygen, mg/L
10
9
8
7
6
5
4
3
2
1
0
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
296
291
286
281
276
River Miles
Predicted minimum
Acute Standard
High Uncertainty
WWTP
Tributary
Diversion

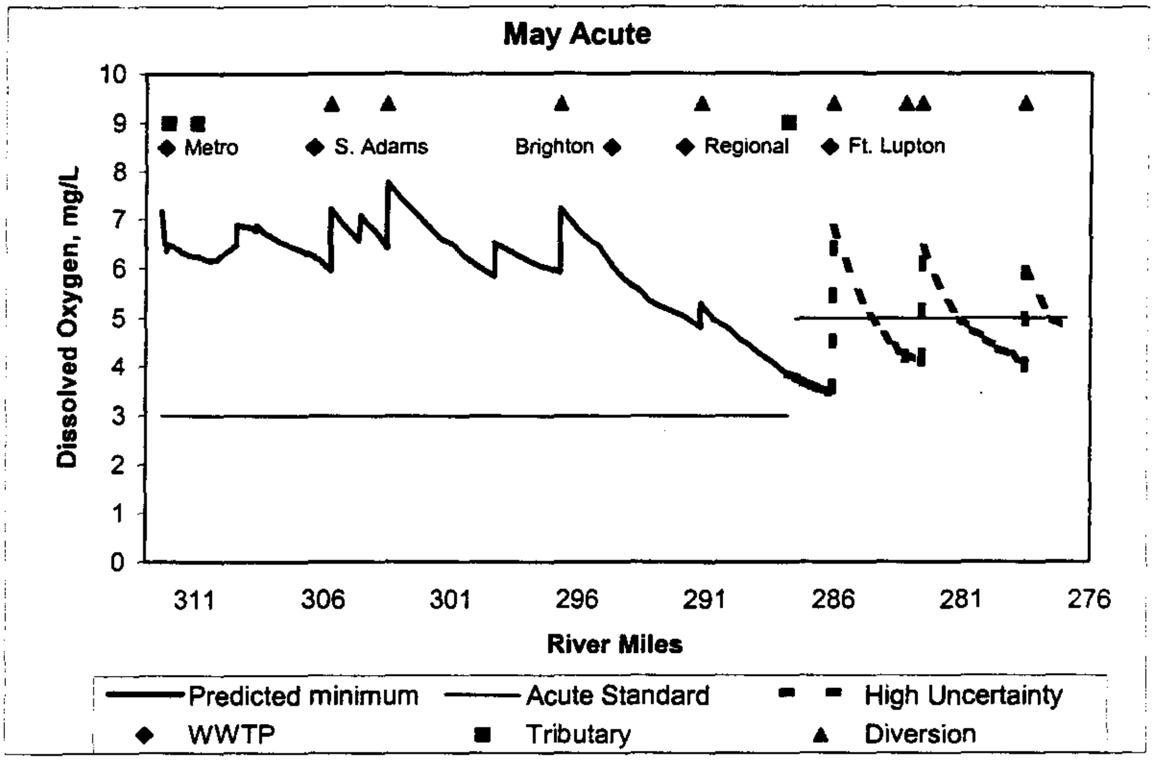

February Chronic
Dissolved Oxygen, mg/L
10
9
8
7
6
5
4
3
2
1
0
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
296
291
286
281
276
River Miles
Predicted average
Chronic Standard
High Uncertainty
WWTP
Tributary
Diversion

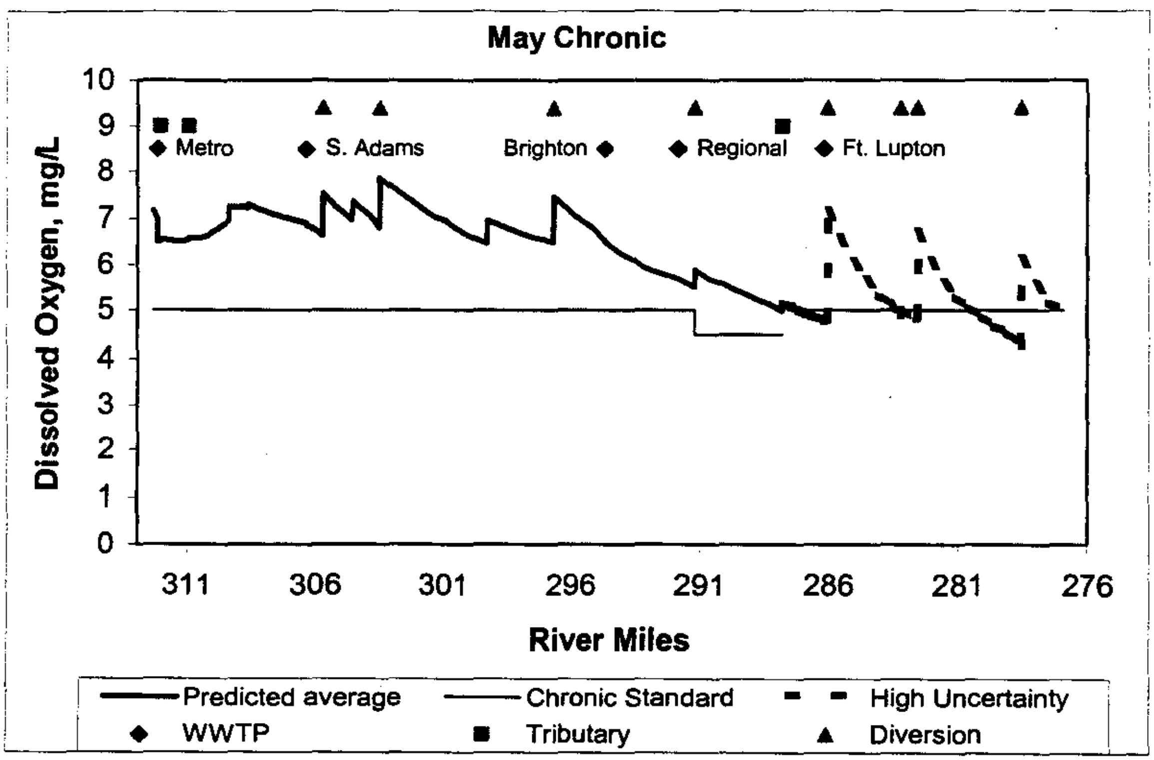

March Acute
Dissolved Oxygen, mg/L
10
9
8
7
6
5
4
3
2
1
0
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
296
291
286
281
276
River Miles
Predicted minimum
Acute Standard
High Uncertainty
WWTP
Tributary
Diversion

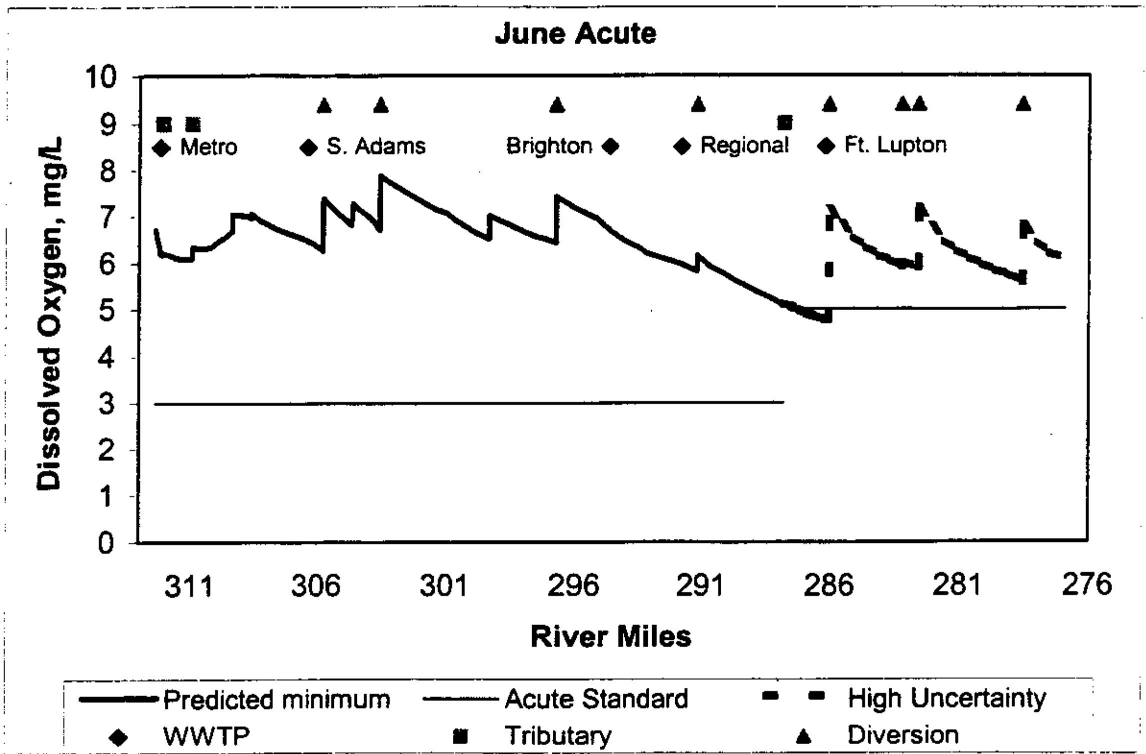

March Chronic
Dissolved Oxygen, mg/L
10
9
8
7
6
5
4
3
2
1
0
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
296
291
286
281
276
River Miles
Predicted average
Chronic Standard
High Uncertainty
WWTP
Tributary
Diversion


April Acute
Dissolved Oxygen, mg/L
River Miles
Metro
S. Adams
Brighton
Regional
Ft. Lupton
Predicted minimum
Acute Standard
High Uncertainty
WWTP
Tributary
Diversion


April Chronic
Dissolved Oxygen, mg/L
River Miles
Metro
S. Adams
Brighton
Regional
Ft. Lupton
Predicted average
Chronic Standard
High Uncertainty
WWTP
Tributary
Diversion


May Acute
Dissolved Oxygen, mg/L
10
9
8
7
6
5
4
3
2
1
0
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
296
291
286
281
276
River Miles
Predicted minimum
Acute Standard
High Uncertainty
WWTP
Tributary
Diversion


May Chronic
Dissolved Oxygen, mg/L
10
9
8
7
6
5
4
3
2
1
0
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
296
291
286
281
276
River Miles
Predicted average
Chronic Standard
High Uncertainty
WWTP
Tributary
Diversion


June Acute
Dissolved Oxygen, mg/L
10
9
8
7
6
5
4
3
2
1
0
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
296
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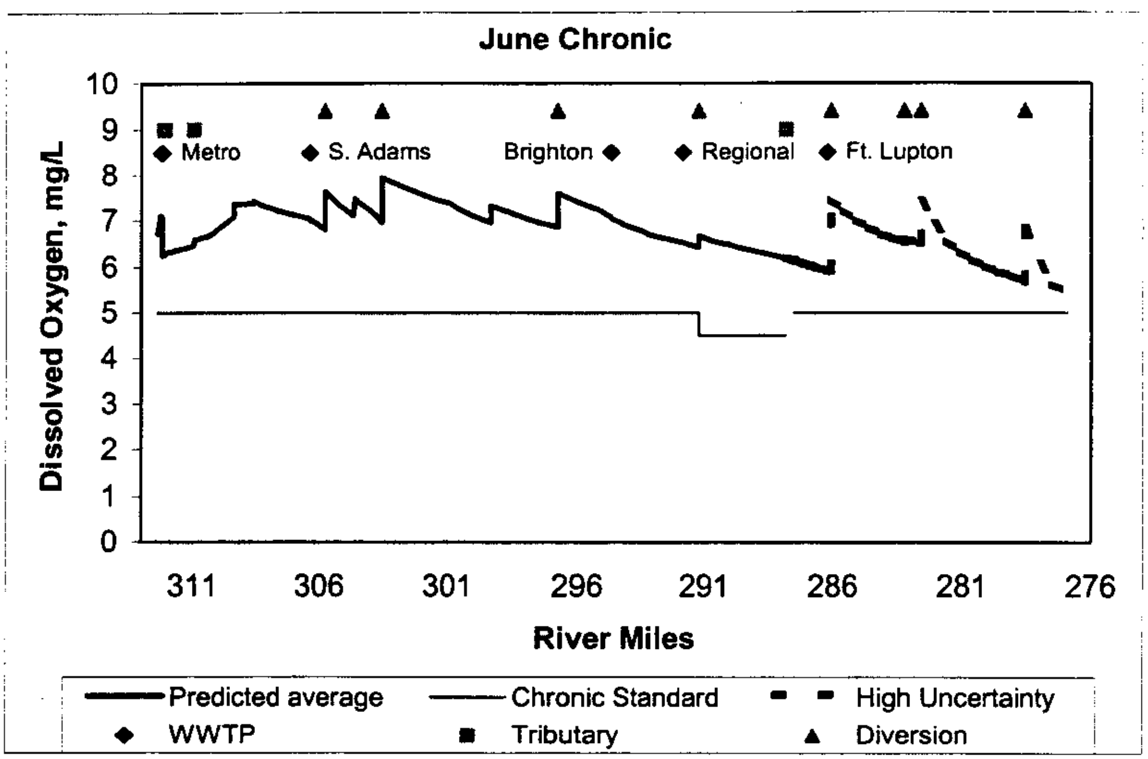
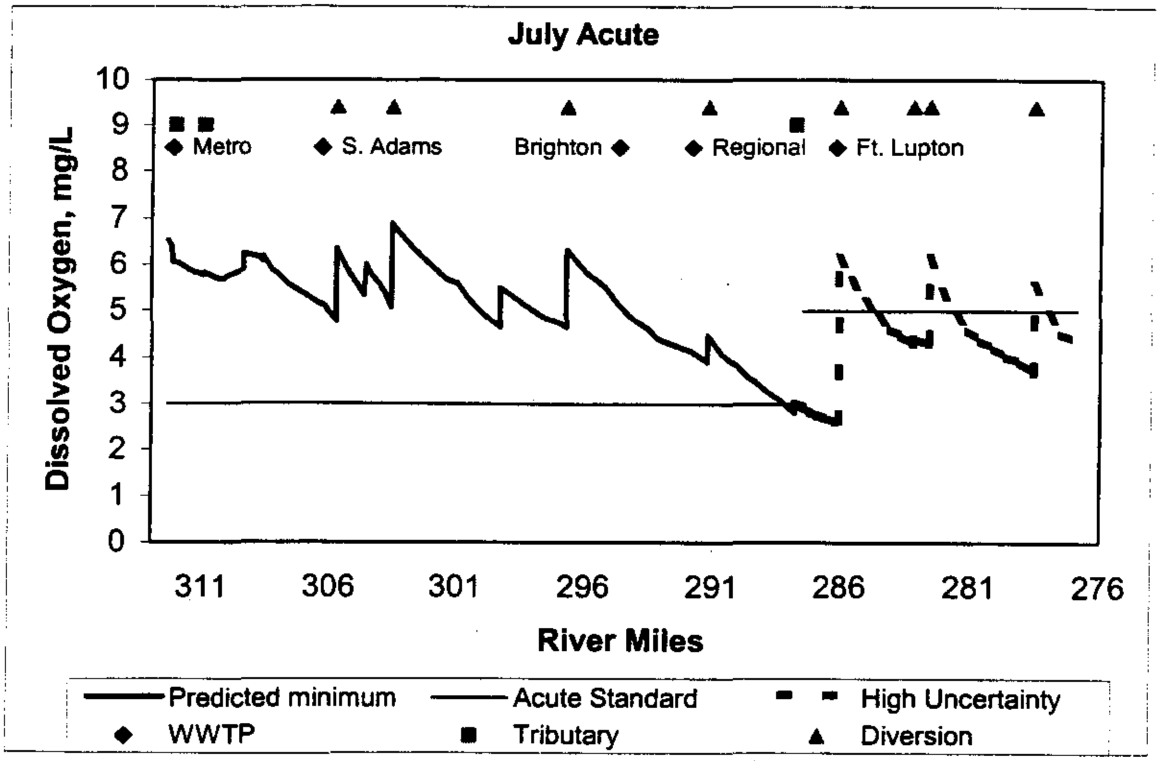
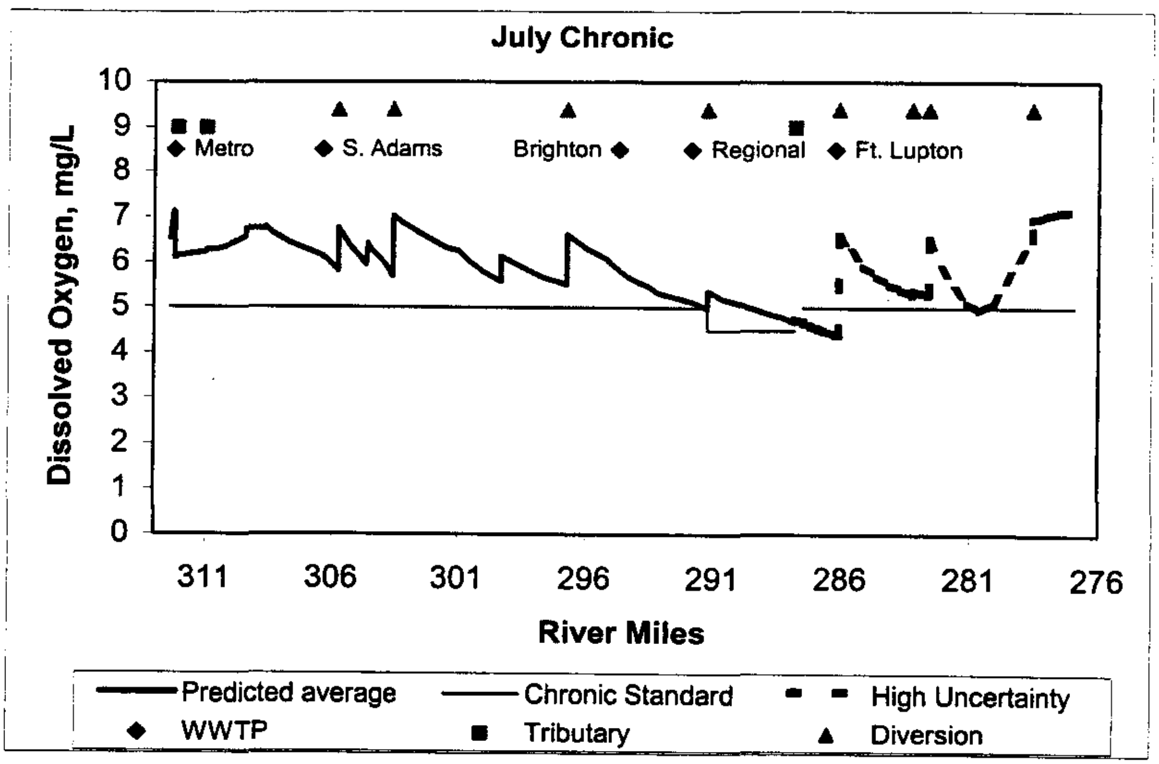
286
281
276
River Miles
Predicted minimum
Acute Standard
High Uncertainty
WWTP
Tributary
Diversion


June Chronic
Dissolved Oxygen, mg/L
10
9
8
7
6
5
4
3
2
1
0
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
296
291
286
281
276
River Miles
Predicted average
Chronic Standard
High Uncertainty
WWTP
Tributary
Diversion


July Acute
Dissolved Oxygen, mg/L
10
9
8
7
6
5
4
3
2
1
0
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
296
291
286
281
276
River Miles
Predicted minimum
Acute Standard
High Uncertainty
WWTP
Tributary
Diversion


July Chronic
Dissolved Oxygen, mg/L
10
9
8
7
6
5
4
3
2
1
0
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
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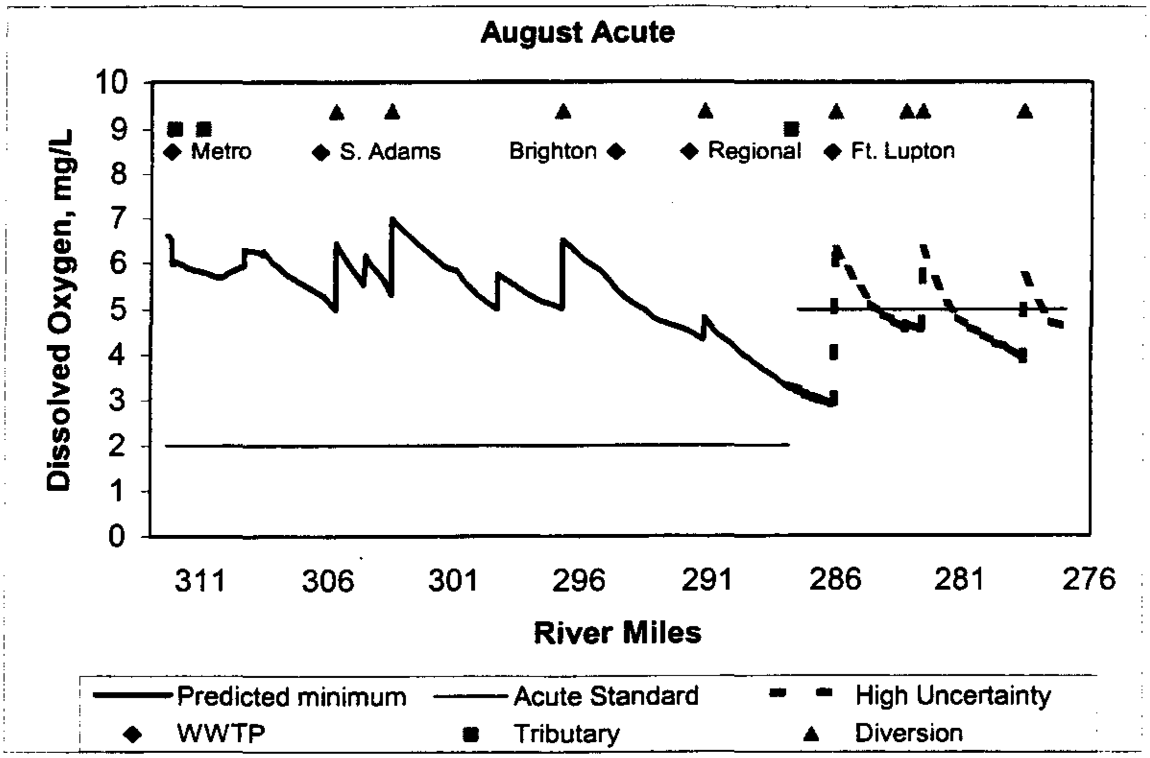
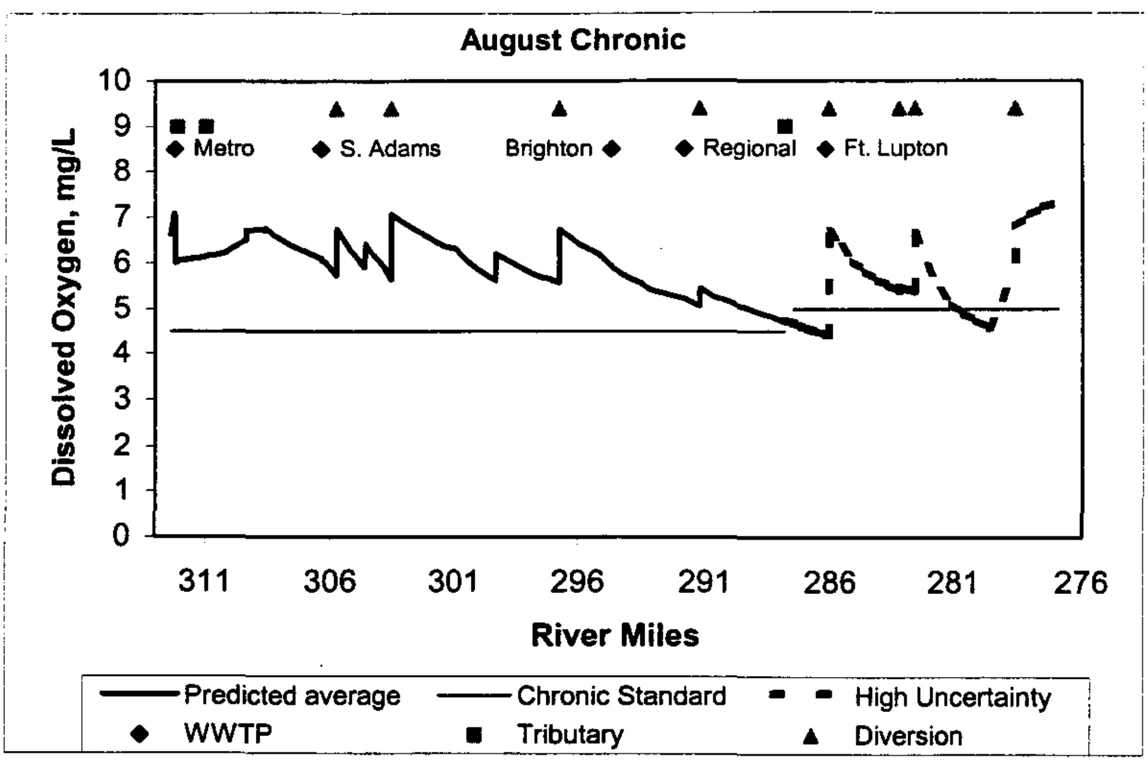
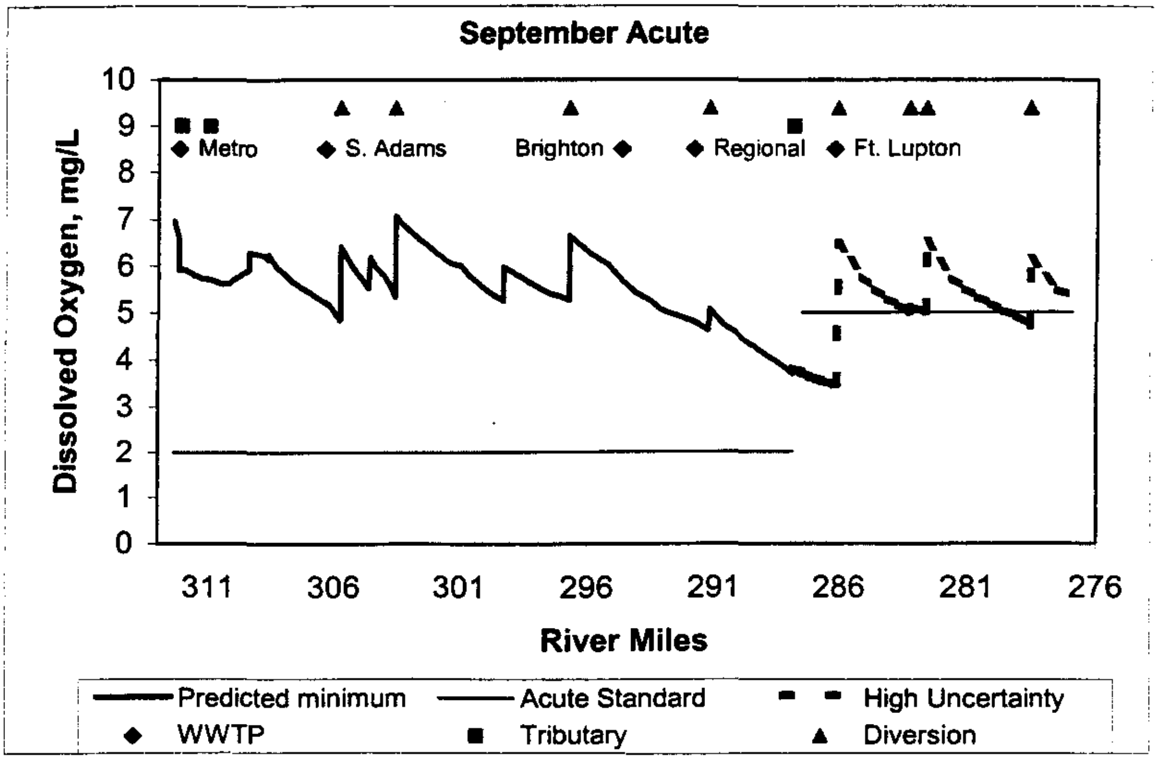
281
276
River Miles
Predicted average
Chronic Standard
High Uncertainty
WWTP
Tributary
Diversion


August Acute
Dissolved Oxygen, mg/L
Metro
S. Adams
Brighton
Regional
Ft. Lupton
River Miles
Predicted minimum
Acute Standard
High Uncertainty
WWTP
Tributary
Diversion


August Chronic
Dissolved Oxygen, mg/L
Metro
S. Adams
Brighton
Regional
Ft. Lupton
River Miles
Predicted average
Chronic Standard
High Uncertainty
WWTP
Tributary
Diversion


September Acute
Dissolved Oxygen, mg/L
10
9
8
7
6
5
4
3
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1
0
Metro
S. Adams
Brighton
Regional
Ft. Lupton
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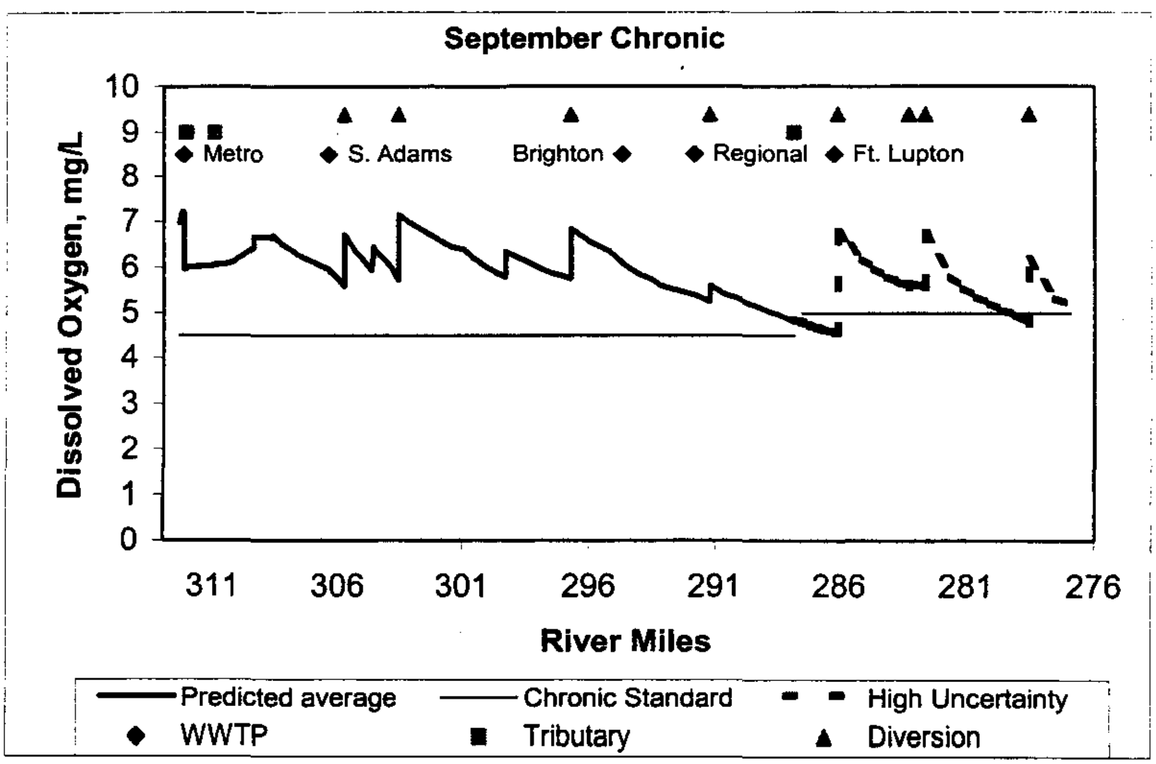
River Miles
Predicted minimum
Acute Standard
High Uncertainty
WWTP
Tributary
Diversion


September Chronic
Dissolved Oxygen, mg/L
10
9
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7
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4
3
2
1
0
Metro
S. Adams
Brighton
Regional
Ft. Lupton
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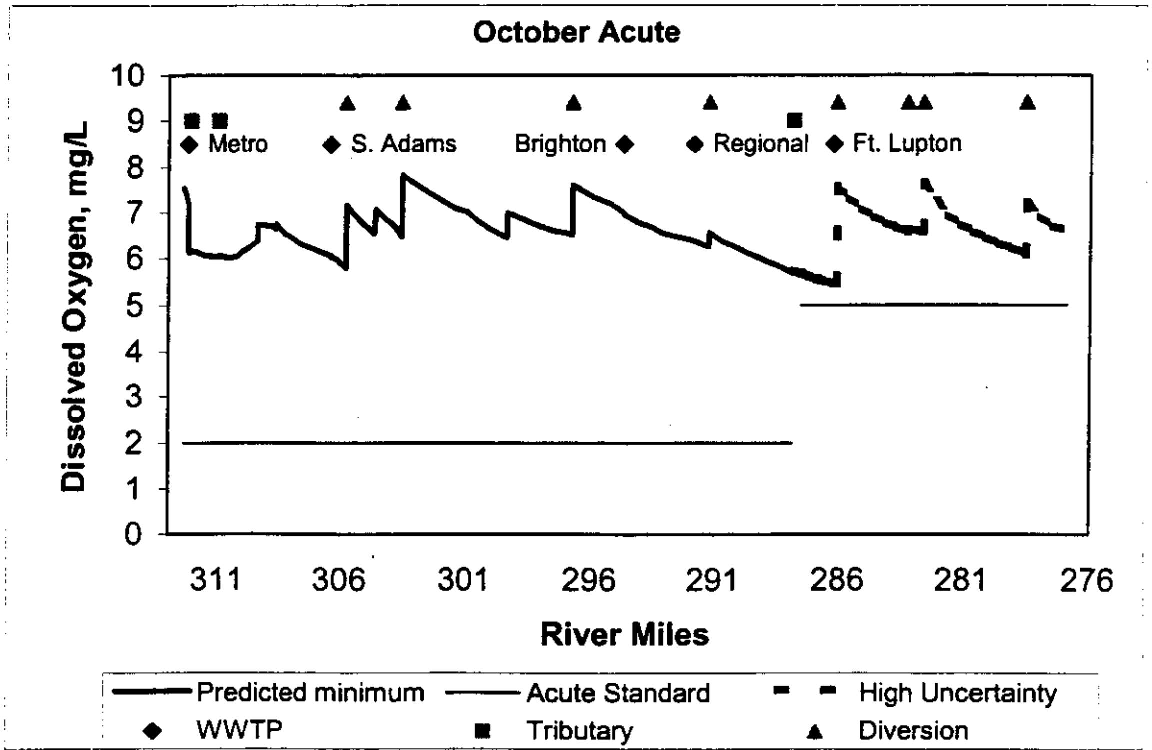
River Miles
Predicted average
Chronic Standard
High Uncertainty
WWTP
Tributary
Diversion


October Acute
Dissolved Oxygen, mg/L
10
9
8
7
6
5
4
3
2
1
0
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
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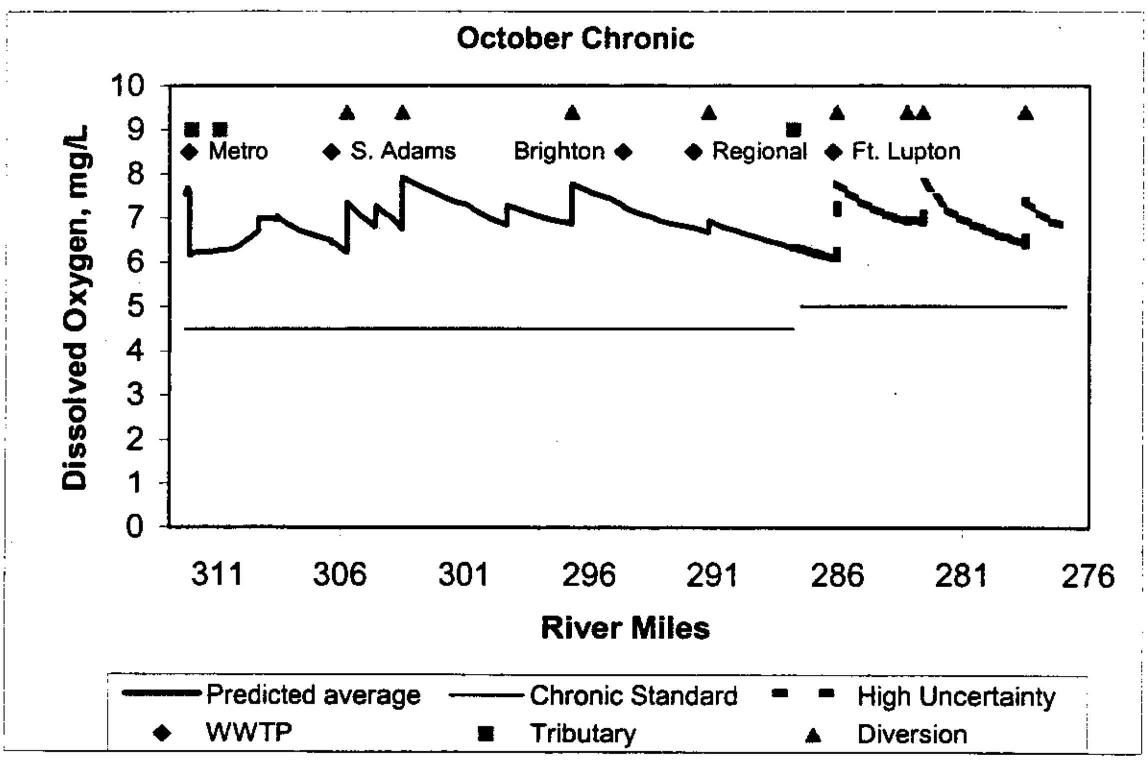
286
281
276
River Miles
Predicted minimum
Acute Standard
High Uncertainty
WWTP
Tributary
Diversion


October Chronic
Dissolved Oxygen, mg/L
10
9
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6
5
4
3
2
1
0
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
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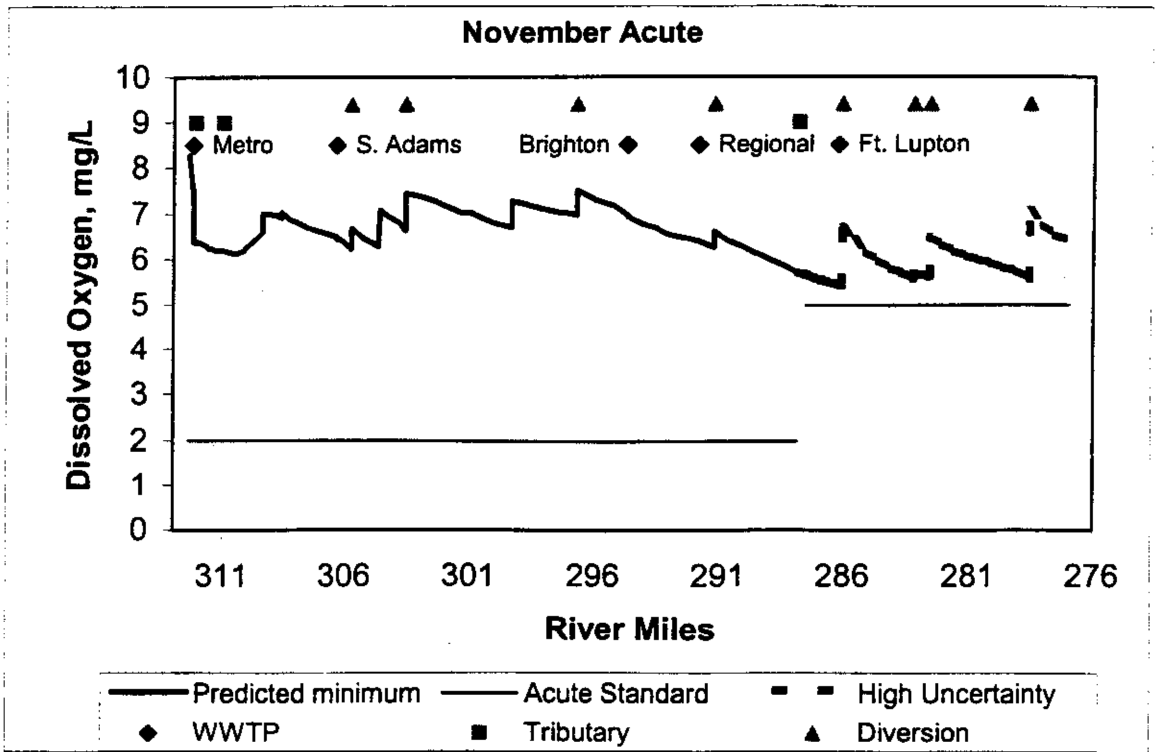
286
281
276
River Miles
Predicted average
Chronic Standard
High Uncertainty
WWTP
Tributary
Diversion


November Acute
Dissolved Oxygen, mg/L
10
9
8
7
6
5
4
3
2
1
0
Metro
S. Adams
Brighton
Regional
Ft. Lupton
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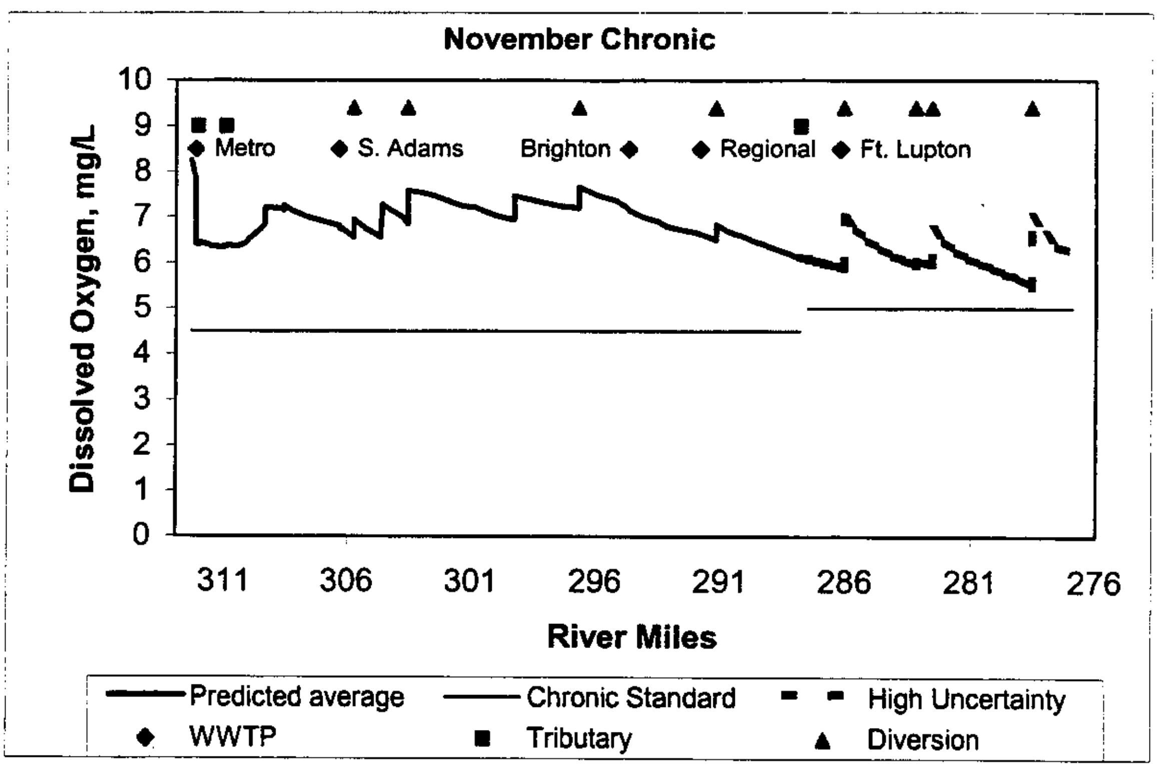
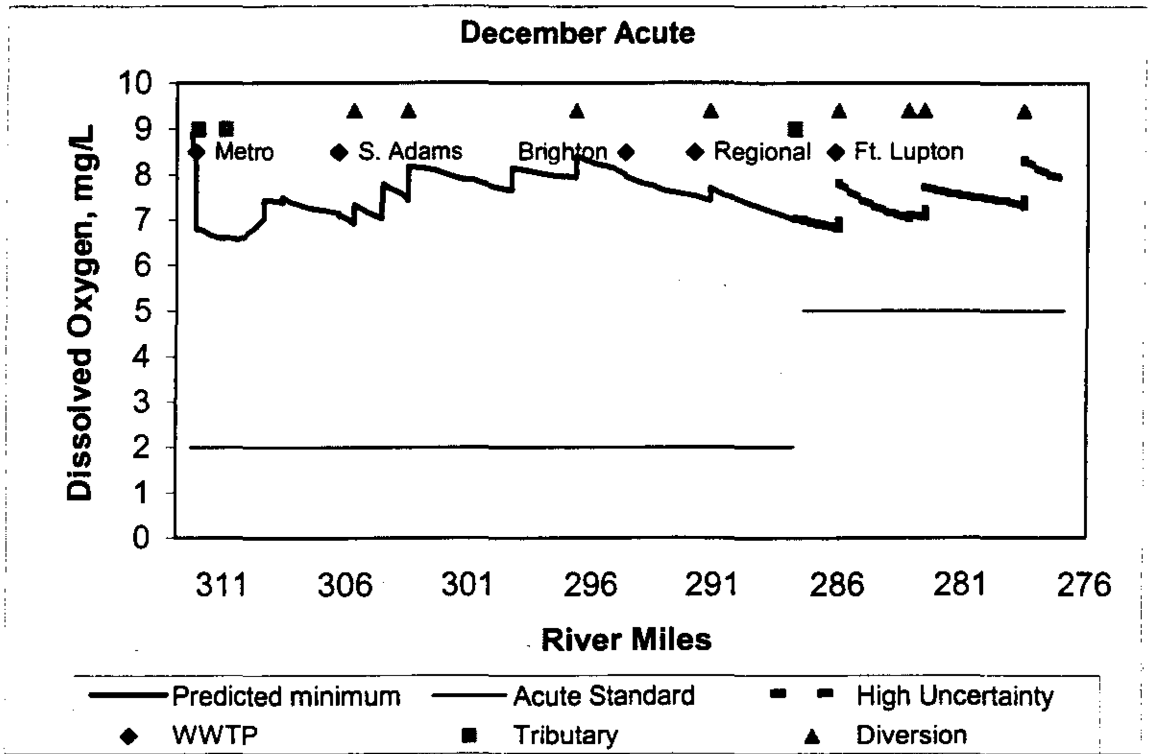
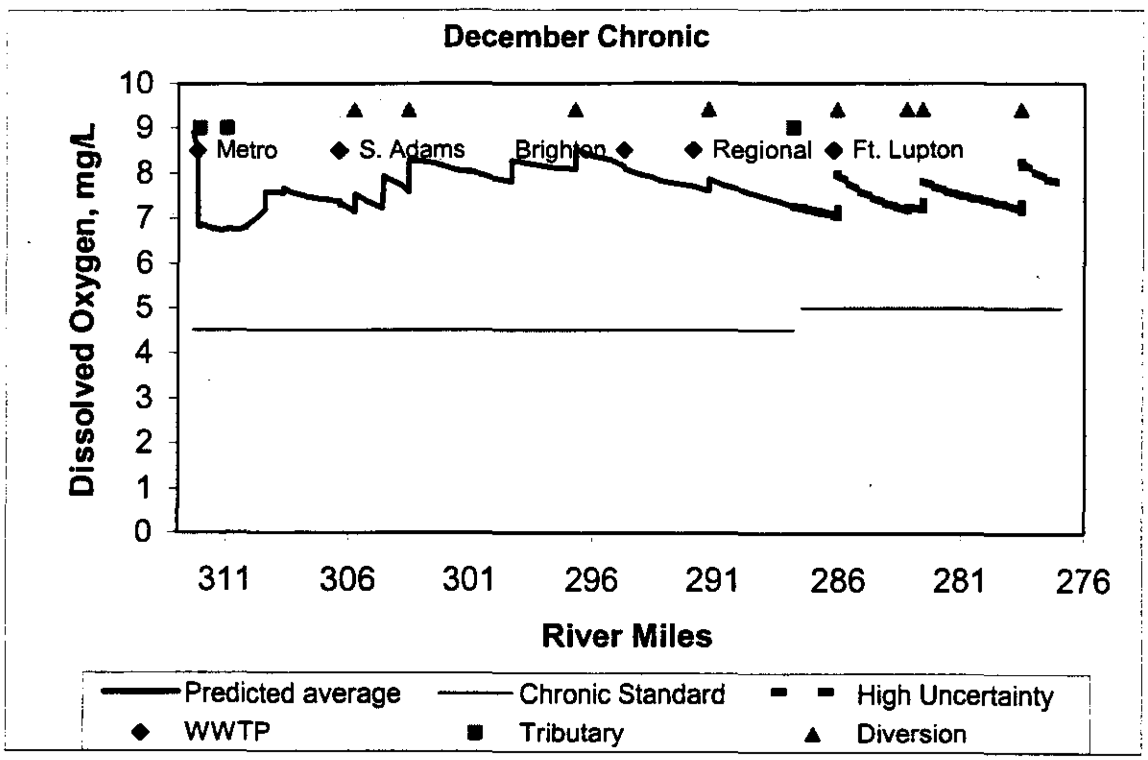
281
276
River Miles
Predicted minimum
Acute Standard
High Uncertainty
WWTP
Tributary
Diversion


November Chronic
Dissolved Oxygen, mg/L
10
9
8
7
6
5
4
3
2
1
0
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
296
291
286
281
276
River Miles
Predicted average
Chronic Standard
High Uncertainty
WWTP
Tributary
Diversion


December Acute
Dissolved Oxygen, mg/L
10
9
8
7
6
5
4
3
2
1
0
Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
296
291
286
281
276
River Miles
Predicted minimum
Acute Standard
High Uncertainty
WWTP
Tributary
Diversion


December Chronic
Dissolved Oxygen, mg/L
10
9
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Metro
S. Adams
Brighton
Regional
Ft. Lupton
311
306
301
296
291
286
281
276
River Miles
Predicted average
Chronic Standard
High Uncertainty
WWTP
Tributary
Diversion

Appendix C

Statistical Relationships between Water Quality Variables Affecting Oxygen Concentrations in the Metro District Effluent

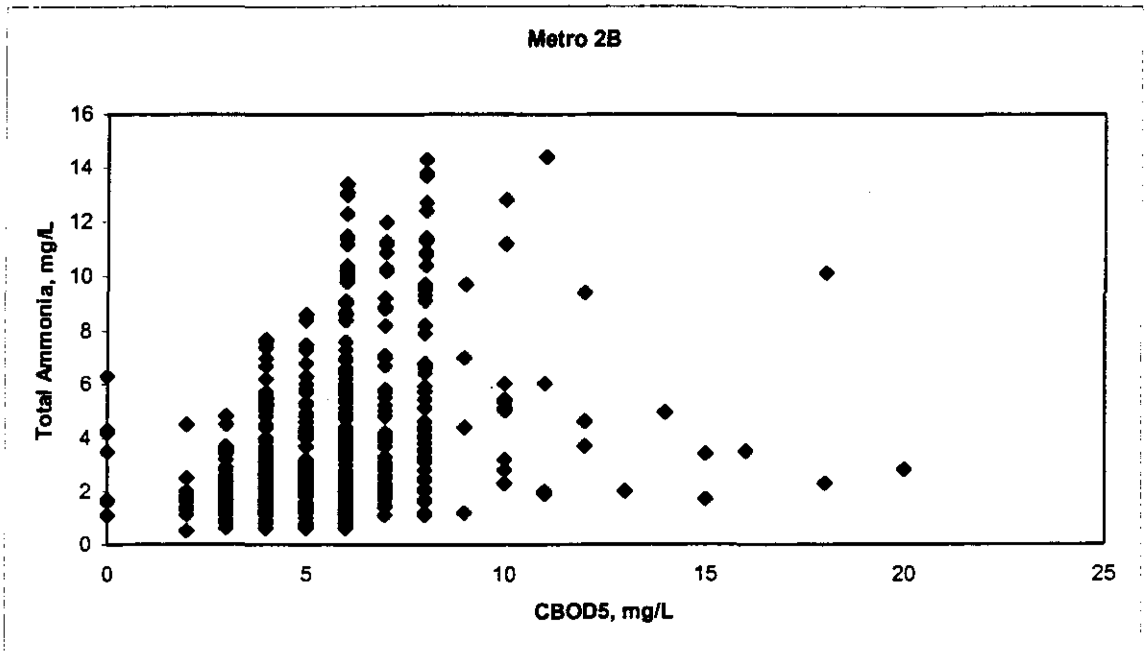


Figure 1. Relationship between total ammonia and CBOD5 in 24-h composite samples from the Metro North complex effluent, 1999-2001.

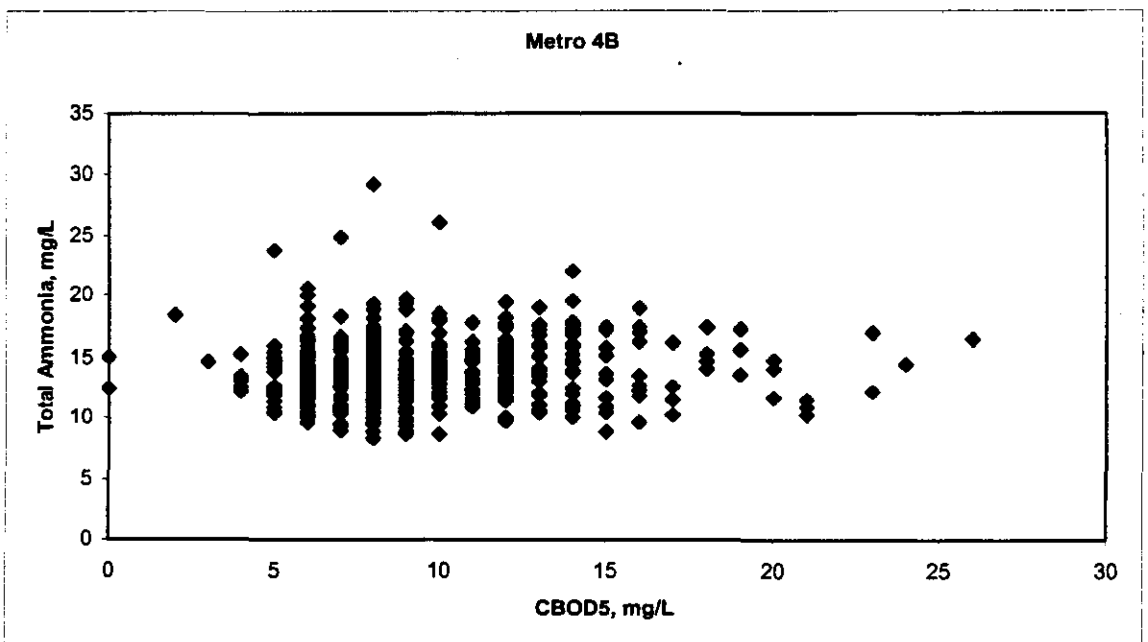


Figure 2. Relationship between total ammonia and CBOD5 in 24-h composite samples from the Metro South complex effluent, 1999-2001.

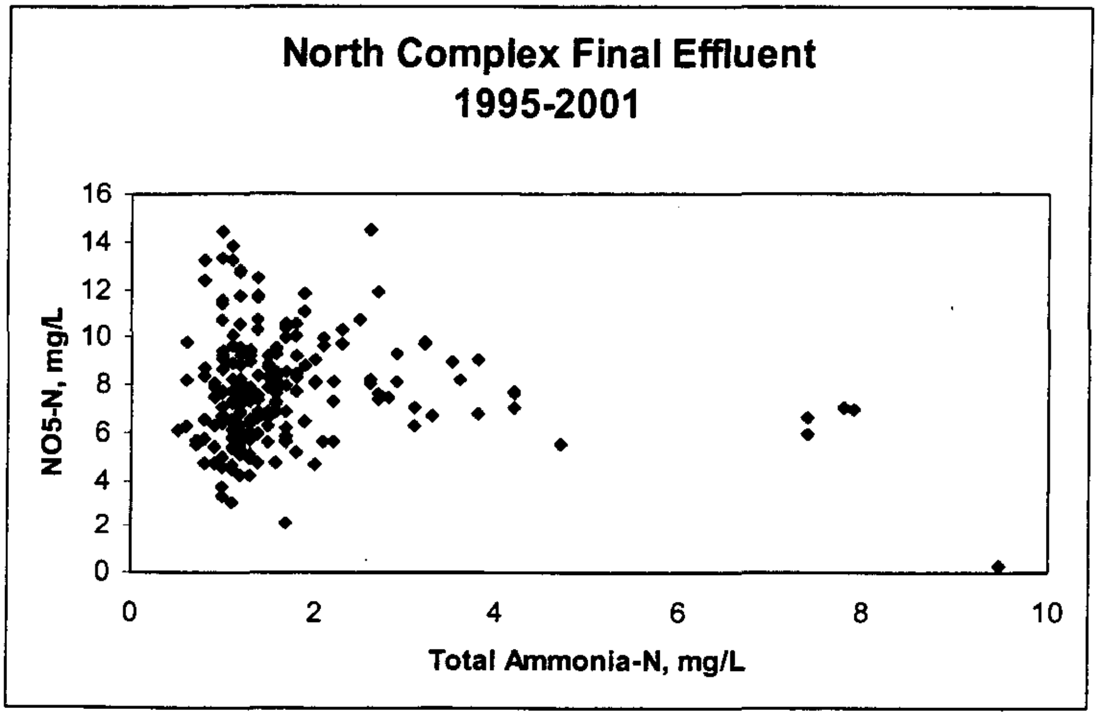


Figure 3. Relationship between nitrate and total ammonia in grab samples from the Metro North complex effluent, 1995-2001.

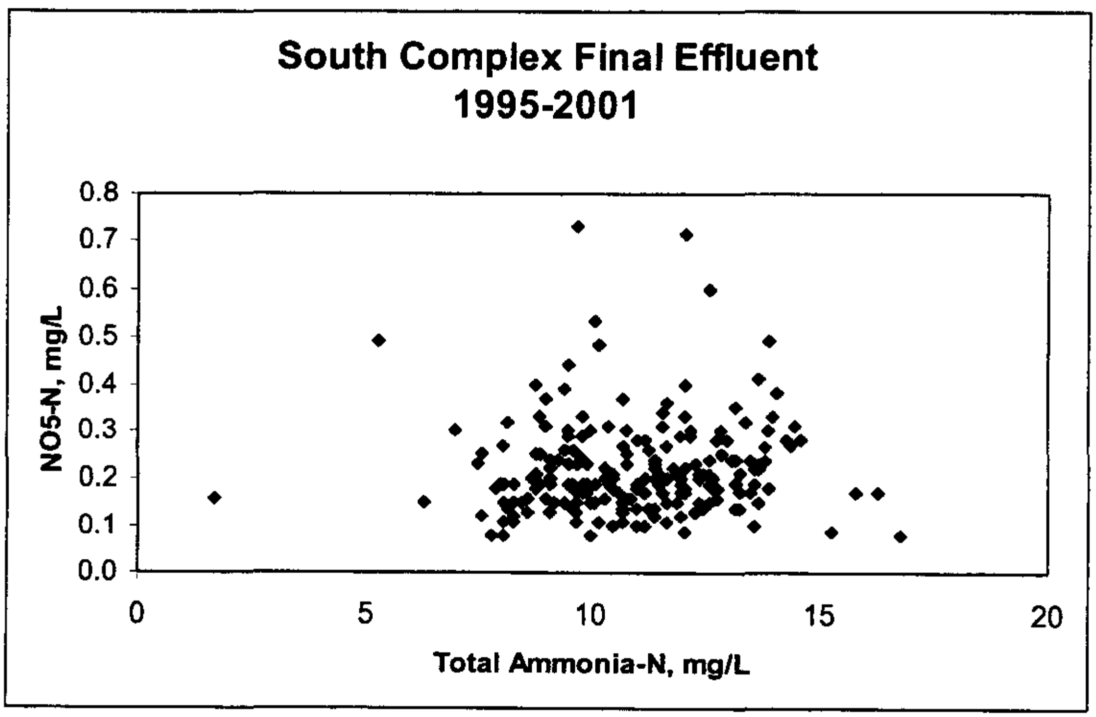


Figure 4. Relationship between nitrate and total ammonia in grab samples from the Metro South complex effluent, 1995-2001.

Appendix D

Segment 15 Water Quality Model Recalibration for 2001 and Use of the Model in Support of Permitting Addendum for Nitrate

Prepared by: William M. Lewis, Jr.
James F. Saunders, III
Date of preparation: May 14, 2002

R/154b

Introduction

Concentrations of nitrate nitrogen are subject to limitation for protection of drinking water supply in Upper South Platte Segment 15. Points of compliance for drinking water supply purposes are the Thornton well fields, which are located just downstream of 78th Avenue, and the Fulton Ditch headgate. Domestic water supply use does not apply to Middle South Platte Segment 1, which is just downstream of Upper South Platte Segment 15. Nitrate concentrations in MSP Segment 1 are of some interest, however, given that nitrate standards could be more broadly applied in the future.

The modelling of water quality conditions in Upper South Platte Segment 15 and Middle South Platte Segment 1 has been described in a recently-released report.[1] The purpose of the present addendum is to report adaptation of the same model to establish effluent limits for nitrate on Segment 15.

Methods

The methods for establishing nitrate concentrations in effluent consistent with nitrate standards on Segment 15 are identical in all respects to the modelling leading up to establishment of limits for unionized ammonia, dissolved oxygen, and CBOD as previously reported, except for establishment of input conditions for projecting nitrate concentrations under future conditions, as described here. Only acute conditions are

[1] Segment 15 Water Quality Model Recalibration for 2001 and Use of the Model in Support of Permitting. William M. Lewis, Jr. and James F. Saunders, III. March 26, 2002.

relevant for evaluation of nitrate. The calibration of the Segment 15 model for ammonia was linked to calibration of the model for nitrate and is described in the original report.

Nitrogen Concentrations in Source Waters and Flow Conditions

Table 1 shows the characteristic nitrate concentrations that are used in modelling, as derived from monitoring information described in the main report. The treatment of seepage water on the basis of alluvial well sampling is as given in the original report.

Month	64th	Sand Creek	Clear Creek	Big Dry Creek	Fort Lupton WWTP	Regional Facility
Jan	6.9	2.9	1.1	9.2	41.8	25.0
Feb	7.6	2.8	1.0	9.2	42.3	25.0
Mar	5.3	2.5	1.1	7.0	41.8	25.0
Apr	3.0	2.1	1.1	4.9	43.6	25.0
May	2.7	1.9	0.9	4.6	40.4	25.0
Jun	2.5	1.7	0.6	4.3	48.1	25.0
Jul	2.3	1.6	0.4	4.0	55.0	25.0
Aug	4.0	3.8	0.8	5.4	30.8	25.0
Sep	3.7	2.2	1.3	5.6	42.0	25.0
Oct	4.3	1.9	1.2	6.4	42.0	25.0
Nov	5.4	3.0	1.3	9.1	42.0	25.0
Dec	6.1	2.9	1.2	9.1	42.0	25.0

*Assumes a 50:50 split of design capacity (north, south).

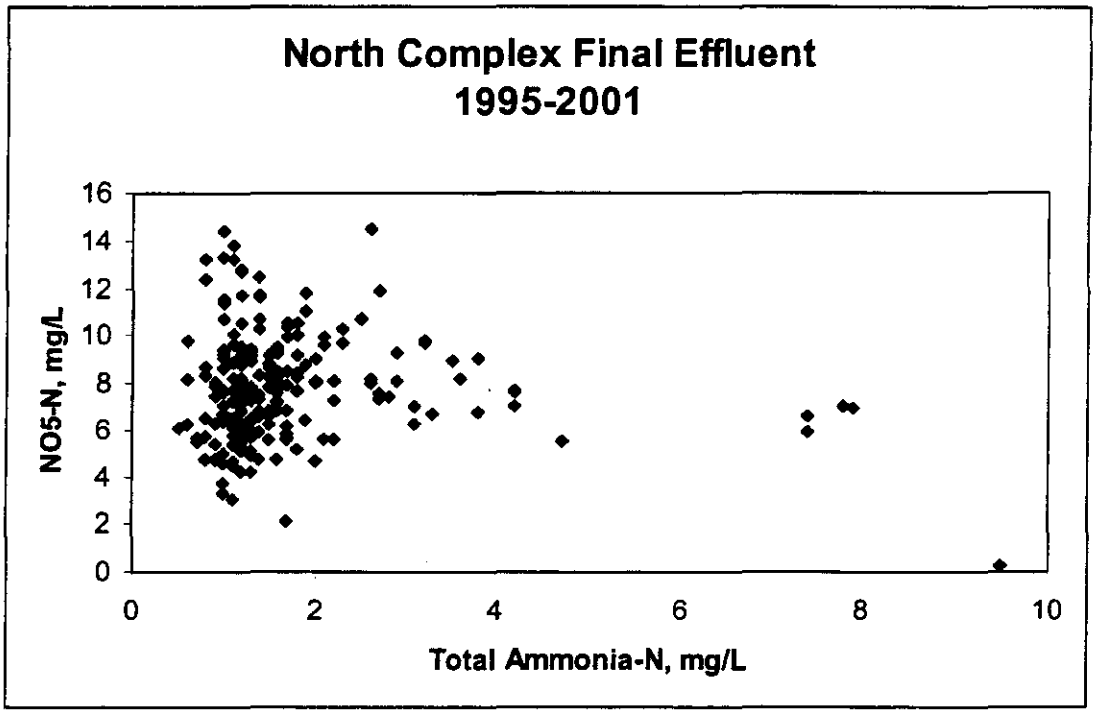
Table 1. Nitrate nitrogen concentrations used to characterize water sources in the Segment 15 Water Quality Model.

Modelling is based on the assumption of capacity effluent flows and acute low-flow conditions as described in the original report. Concentrations of total ammonia are set to characteristic values for Metro because statistical studies of the relationship between nitrate and total ammonia show no statistical association between these two water-quality variables (Figure 1). Ammonia concentrations for South Adams and Brighton were set to 25 mg/L, as given in the previous report. Effluent limits were established by adjustment of the Metro District's nitrate concentrations for effluent to a level consistent with stream standards and subsequent adjustment of effluent concentrations for South Adams and Brighton as appropriate to maintain compliance downstream and to use any assimilative capacity developing below the point of discharge for the Metro District. Nitrate concentrations in effluent were capped at 25 mg/L.

Results

Figure 2 shows the projected nitrate concentrations in February and September, when the conditions for discharging nitrate are most stringent (i.e., when requirements on the dischargers are highest). For these and other months, nitrate concentrations show an initial peak just at the point of Metro's discharge reflecting the nitrate content of the Metro effluent. Below Metro, the concentration decreases because of ungaged flow and flow from Sand Creek and Clear Creek, all of which have nitrate concentrations well below 10 mg/L, and because of denitrification. Nitrification downstream of Metro adds nitrate continuously, but the effects of dilution and denitrification are stronger in combination than the effect of nitrification between the Metro outfall and the South Adams outfall.

At the South Adams outfall, there is a second peak caused by the release of effluent from the South Adams Wastewater Treatment Plant. This is followed by a decline due to processes already mentioned.



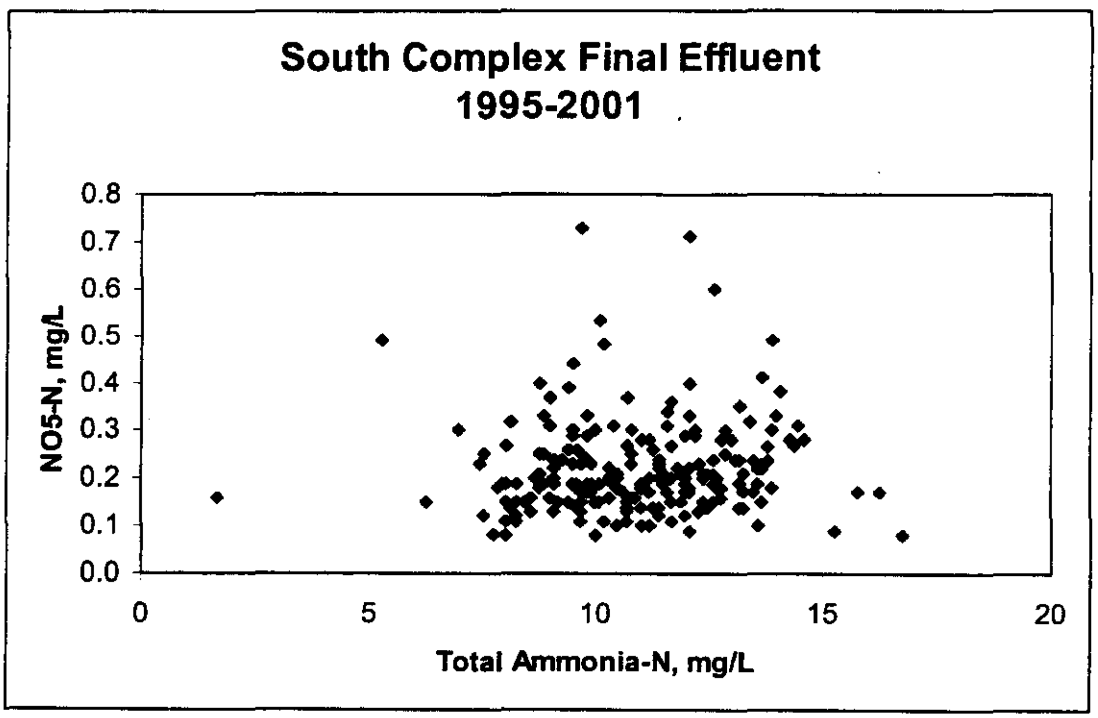


Figure 1. Relationship of nitrate to total ammonia in Metro effluent (1995-2001).

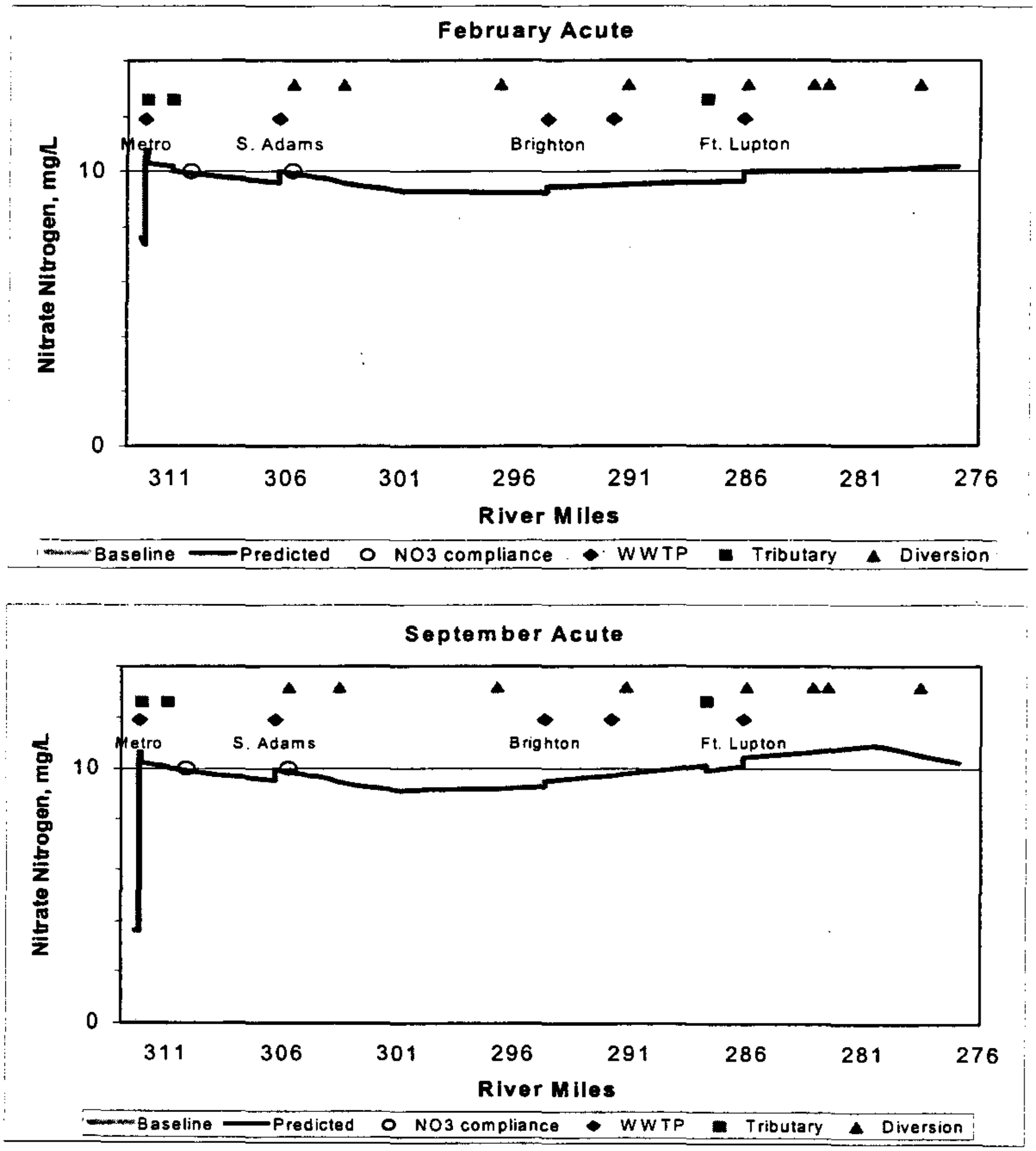


Figure 2. Predictions of nitrate nitrogen in Segment 15 during February and September with effluent concentrations adjusted as necessary to bring the river to 10 mg/L at the two points of compliance indicated on the graphs.

The Brighton effluent causes yet another increase. Downstream of Brighton, however, there is a steady increase rather than a decrease in nitrate concentrations. This is explained by the predominance of nitrification over dilution and denitrification over this reach of the river. Just below Segment 15, the Fort Lupton WWTP also causes an increase, and seepage has increasing nitrate concentrations in the downstream direction. Although Fort Lupton has a small discharge, it characteristically has high nitrate concentrations, which is the reason for the notable increase below its point of discharge.

Below Fort Lupton, nitrate concentrations continue to increase gradually because of a predominance of nitrification over denitrification and dilution. The increase would be expected to terminate when ammonia has been exhausted by a nitrification process. Although this varies with modelling conditions, it generally occurs near mile 276, i.e., at the terminal end of the graph shown in Figure 2.

The concentrations shown in Figure 2 have been adjusted through manipulation of the concentrations of nitrate assumed to be present in the effluent for the Metro District and for South Adams. First, the Metro District's concentrations were adjusted to bring the river to 10 mg/L at the first point of compliance, i.e., the Thornton Well Fields. South Adams benefits downstream from increased assimilative capacity that develops between the first point of compliance and the second point of compliance. The concentrations for the South Adams effluent were adjusted to bring the river to 10 mg/L at the second point of compliance, i.e., at the Fulton Ditch headgate. No adjustments were made to concentrations for Brighton or Fort Lupton because there are no points of compliance below these facilities.

The Lower South Platte Regional Facility also was modeled for its effect on concentrations of nitrate. No compliance requirements for nitrate are known (no drinking water classification), except for those related to agricultural use, which are very high. The 10 mg/L standard for municipal supply is used here as a point of reference, however. As shown in Figure 3, effects of the regional plant begin as far upstream as Metro because there would be a decline in Metro's discharge volume and elimination of the Brighton discharge if the regional plant were completed as planned. The Lower South Platte Regional Plant would raise nitrate concentrations significantly. The reason for the rise has to do with nitrification, which is incorporated into assumptions for operation of the Lower South Platte Regional Plant (assumption of 25 mg/L nitrate N is from Carollo Engineers). The rise carries nitrate concentrations above 10 mg/L in MSP Segment 1 under acute conditions. As explained in a previous section, a peak would be reached due to complete depletion of ammonia from the river and subsequent dominance of denitrification as an influence on nitrate concentrations (see September, mile 282, Figure 3). Table 2 shows the final results for modelling of nitrate.

	Metro Combined Effluent*	South Adams Effluent	Brighton Effluent
January	11.4	23.0	25.0
February	10.9	23.0	25.0
March	11.1	20.0	25.0
April	11.2	23.0	25.0
May	11.1	25.0	25.0
June	14.5	25.0	25.0
July	11.6	25.0	25.0
August	11.7	23.0	25.0
September	10.9	25.0	25.0
October	11.1	25.0	25.0
November	10.9	24.0	25.0
December	11.1	23.0	25.0

* Assumed equal split between north and south effluents

Table 2. Effluent concentrations (acute) of nitrate necessary for compliance with a 10 mg/L standard for nitrate on the Upper South Platte River Segment 15, as explained in the text.

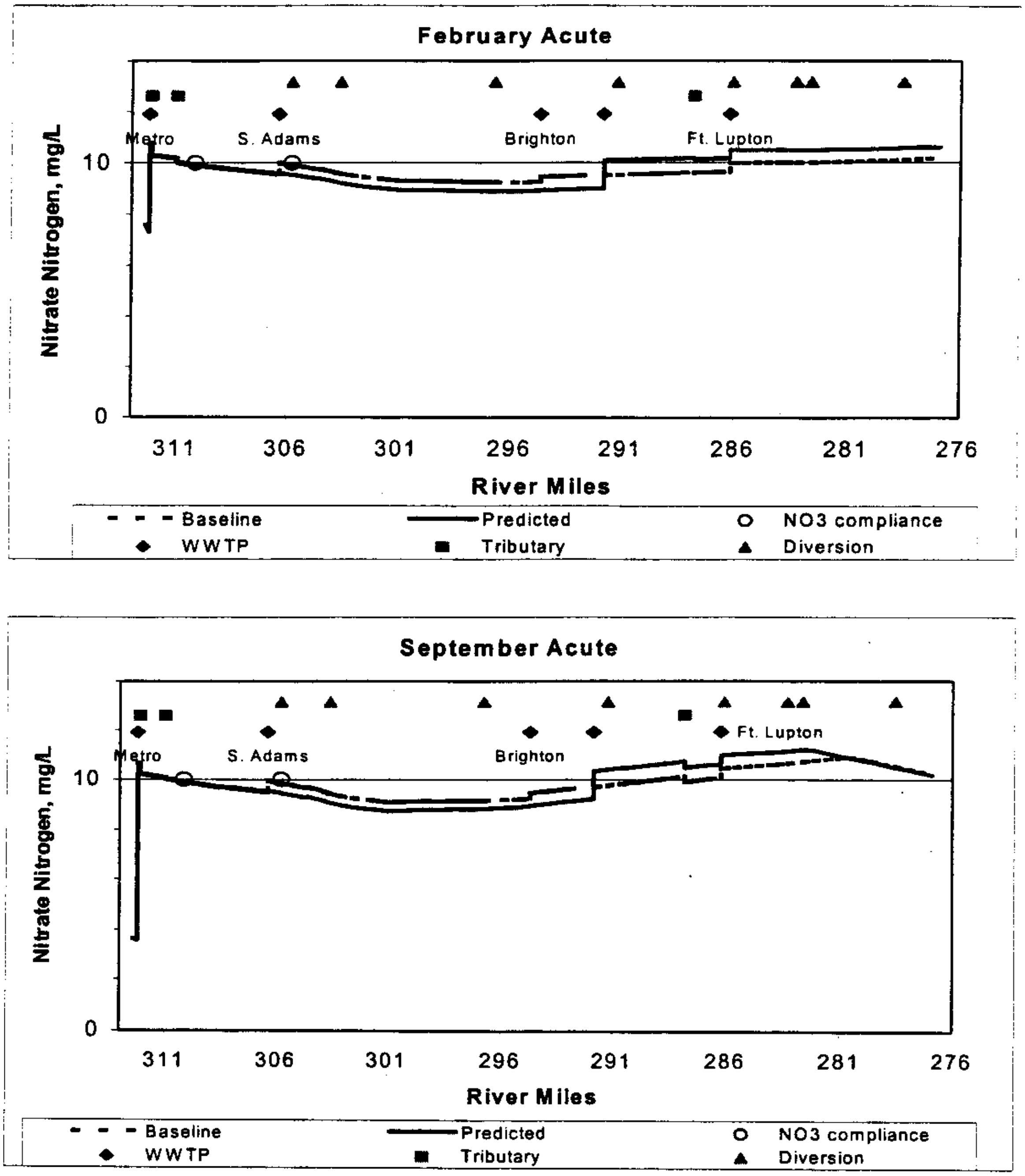


Figure 3. Predictions of nitrate nitrogen in February and September with effluent concentrations adjusted to bring the river to 10 mg/L at the two points of compliance indicated on the graphs. The location of the projected regional facility is shown and is assumed to be operating under conditions expected for year 2020 (solid line). Baseline is for conditions without the regional plant.

Appendix E

South Platte River Segment 15 Water Quality Assessment

Analysis and Modelling in Support of Permitting on Lower Sand Creek and the Upper Portion of Segment 15, South Platte River

Prepared by: William M. Lewis, Jr.
James F. Saunders, III
Date of Preparation: May 24, 2001

R/91

Introduction

The quality of surface waters near the junction of Sand Creek with the South Platte River is difficult to evaluate because of the commingling of five wastewater effluent discharges of diverse types in this area, as described below. The purpose of this report is to bring together information on hydrology and water quality as necessary to estimate the combined influences of these five effluent discharges on the water quality of lower Sand Creek and Segment 15 of the South Platte River, and to show how this information can be used in allocating the assimilative capacity of the South Platte River and lower Sand Creek to each of the five discharges for all constituents of concern. The projection of water quality conditions at regulatory low flows and with the assumption of all discharges functioning at full capacity is accomplished through the use of a water quality model (the Sand Creek/South Platte Segment15 Assessment Model, referred to here as the "Assessment Model"). The model can be used flexibly in exploring alternative allocation strategies consistent with stream standards. All of the important assumptions involved in the analyses and modelling reported here were discussed by the Assessment Working Group, which included representatives of the dischargers and of the CDPHE Permits Unit.

Site Description

Sand Creek is a tributary of the South Platte River that joins the South Platte from the east just below 64th Avenue in Commerce City (Figure 1). The watershed has an area of 191 square miles; it includes portions of the City of Aurora, the City and County of Denver, and Commerce City as well as substantial area outside the metropolitan zone.

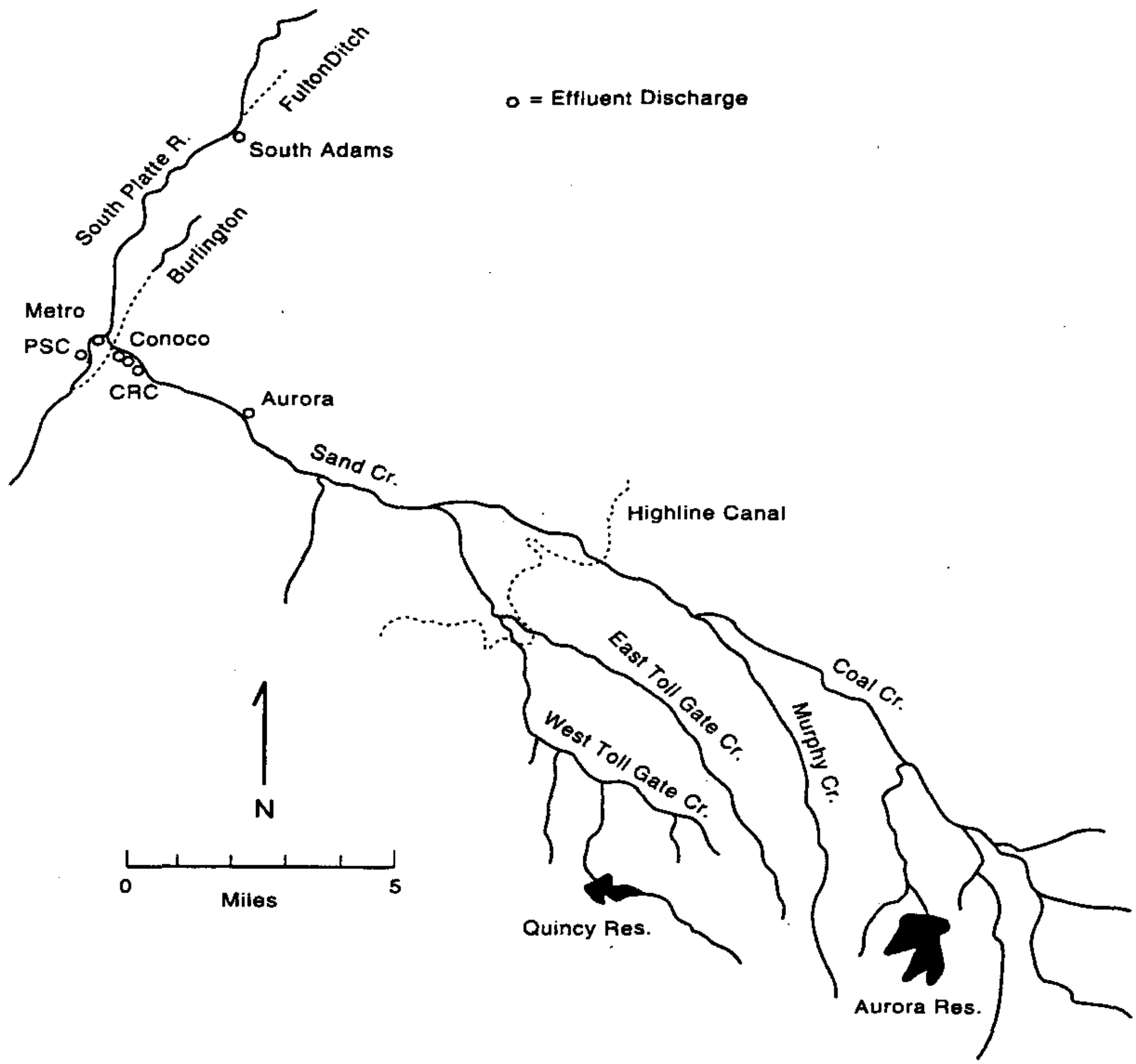


Figure 1. Map of the assessment area.

Sand Creek carries not only its native flow, which originates primarily from spring snowmelt or summer storms, but also water imported from other drainages as domestic and commercial water supply or as agricultural water via the Farmers Highline Canal. Although Sand Creek originally was an ephemeral stream, as indicated by historical photography, it now sustains constant flow near the mouth because of the presence of imported water, which originates from point sources and non-point sources at all times of the year.

The quality of water in Sand Creek is influenced by natural water sources lying outside the metropolitan zone, by runoff and alluvial flow originating in the urbanized zone, by seepage and releases from the Highline Canal, and by effluent discharges. The effluent discharges include the municipal discharge of the City of Aurora and three discharges from two petroleum refineries near the mouth of Sand Creek (Figure 1).

Influences on the water quality of Sand Creek are under study in accordance with an agreement concerning the recently adopted Temporary Modification of the selenium standard for Sand Creek and Segment 15 of the South Platte River. In addition, there will be future permit renewals for dischargers in the upper portions of Sand Creek. Completion of the studies of selenium and future permits in the upper portions of Sand Creek will require considerable additional data on water quality along the length of Sand Creek. For purposes of the present assessment, the focus for Sand Creek is on the lowermost mile, where the refinery discharges occur and where water quality becomes an important issue for preparation of permits on point-source discharges to the South Platte River near the confluence of Sand Creek with the South Platte. For the present assessment, the combined upstream influences on the water quality of Sand Creek are taken into account through water quality data for a point just upstream of the refinery discharges. The water quality at this point on Sand Creek would reflect the influence of Aurora, natural conditions, and the composite of anthropogenic non-point sources affecting Sand Creek. The water quality conditions above the refinery discharges are an important determinant of the concentrations of regulated substances in the refinery discharges that would be consistent with water quality standards.

Segment 15 of the South Platte River begins approximately two miles above the confluence of Sand Creek with the South Platte River, at the Burlington Ditch (Burlington – O'Brian Canal) headgate. Although Segments 14 and 15 are connected hydrologically, the quality of water in Segment 14 is of little relevance to that of Segment 15 under low flow conditions, which are the critical ones for issuance of permits, because of the removal of water from Segment 14 by the Burlington Ditch. Because of this diversion, low flows upstream of the Xcel Cherokee discharge are only a few cfs. Other influences include groundwater (seepage) and local drainage entering Segment 15 downstream of the Burlington Ditch. Because all source flows are small, effluent discharges to the upper end of Segment 15 are the main determinant of the quality of Segment 15 as it reaches Sand Creek at low flow. The relevant discharges are those of the Xcel Energy Cherokee facility (formerly Public Service Company of Colorado) and that of the Metro Wastewater Reclamation District (Metro).

Because Sand Creek enters the South Platte only a short distance below the Cherokee and Metro District outfalls, the low flow characteristics of Sand Creek, including refinery discharges, must be considered in the preparation of NPDES permits. Except for ammonia, the critical point for compliance with water quality standards (point of maximum concentration relative to the standard) is just below the point where all five effluents come together. Below the confluence of the five discharges (Cherokee, Metro, three refinery discharges), the accrual of seepage water and flow from Clear Creek dilute constituents delivered to the South Platte by the combined effluent flows, thus restoring assimilative capacity as distance increases below Sand Creek. For this reason, it is not necessary to consider quantitatively as part of this assessment the downstream effluent discharges to the South Platte (South Adams, Brighton, and Fort Lupton).

Ammonia is the one exception to the generalization that critical conditions occur close to the point of mixing for the effluents. Because pH rises at increasing distances from municipal outfalls, the critical point (i.e., the point of highest concentration) for unionized ammonia may lie considerably downstream of an outfall. Thus, ammonia must be treated separately from other substances mentioned in this report.

Hydrology and Estimation of Low Flows

Wastewater Discharges

Discharge values for capacity at each of the five wastewater sources are needed for construction of flows relevant to permitting. These values are listed in Table 2.

Two general permits are active for the refineries; they are for storm water. Only one brief flow was recorded from these sources since 1996 (J. Kubic, CDPHE, personal communication). Therefore, the general permits are considered irrelevant to this assessment.

Upstream Flows for Sand Creek and South Platte Segment 15

The hydrology of the lower portion of Sand Creek is complicated by the presence of the Burlington Ditch. The headgate of the ditch is located on the South Platte River at

52nd Avenue. When the ditch headgate is open to the South Platte River, water passes through the ditch toward Sand Creek and then underneath the creek by means of an inverted siphon. Flow in the ditch may be augmented by Denver Water and the Farmers Reservoir and Irrigation Company, which may by joint arrangement with Metro pump effluent from the Metro District's treated wastewater into the ditch.

At times, some of the flow reaching the siphon at Sand Creek by way of the Burlington Ditch is diverted to Sand Creek through a radial gate. This gate is used in regulating the flow of the Burlington Ditch, which is measured by a gaging station just beyond the downstream end of the siphon that crosses Sand Creek. The bypass water entering Sand Creek from the ditch may consist of water from the South Platte River, effluent from the Metro District, or a mixture of these.

Because the release of water from the Burlington Ditch augments the flow of Sand Creek, Sand Creek will not reach a low flow condition as long as water is being bypassed. Because the refinery discharges are regulated by the most stringent conditions, which coincide with the lowest flows, conditions that prevail during periods of bypass from the Burlington Ditch will not affect the analysis.

Discharge near the mouth of Sand Creek has been measured by USGS gage between 1992 and the present. Between 1992 and 1998, the gage was situated below the Burlington Ditch discharge, and thus would have included the flow of Sand Creek above the refineries, the amount of water discharged by the refineries, and any release that might have been occurring from the Burlington Ditch. In 1998, the gage was moved to a point above the Burlington Ditch. This is a better location for the gage in terms of stream cross section, and also allows better separation of contributions to flow at the mouth. In reporting flow at the mouth of Sand Creek, however, the USGS uses the sum of the Sand Creek gage reading and the estimated release from Burlington into Sand Creek.

In its water quality assessment of May 12, 2000, CDPHE staff used the Sand Creek gage record between 1992 and 1998 plus general information on the discharges from the refinery effluents to estimate the upstream chronic flow above the refinery discharges as 8.6 cfs and the upstream acute low flow as 2.9 cfs.

For the present analysis, daily records were assembled for the interval 1994 – 2000 for the Sand Creek gage and for the individual refinery effluent discharges (daily records of these discharges are not available prior to 1994). For each day, the refinery discharges were subtracted from the flow at the gage to yield an estimate of flow above the refinery discharges. A plot of these flows showed anomalous flows for a few days centering on 4 July 1996 (Figure 2). It is likely that these anomalous flows resulted from problems with the gage or work in the channel, rather than natural climatic events. For this reason, dates showing flows lower than 6.8 cfs at the Sand Creek gage (27 June, 1 July through 4 July 1996) were set to 6.8 cfs. DFLOW analysis following this adjustment of the anomalous flows yielded an acute low flow of 3.5 cfs and a chronic low flow of 10.2 cfs (Table 2). If the anomalous low flows had not been eliminated, the acute low flow would have been 2.3 cfs and the chronic low flow would have been 9.3 cfs.

Another type of low flow also can be calculated for the mouth of Sand Creek. If discharges to Sand Creek are regulated primarily on the basis of their potential effect on South Platte Segment 15, then low flow values hydrologically consistent with the DFLOW values for Segment 15 should be used for Sand Creek. The situation arises if Sand Creek below the refinery discharges is entirely taken up by a regulatory mixing

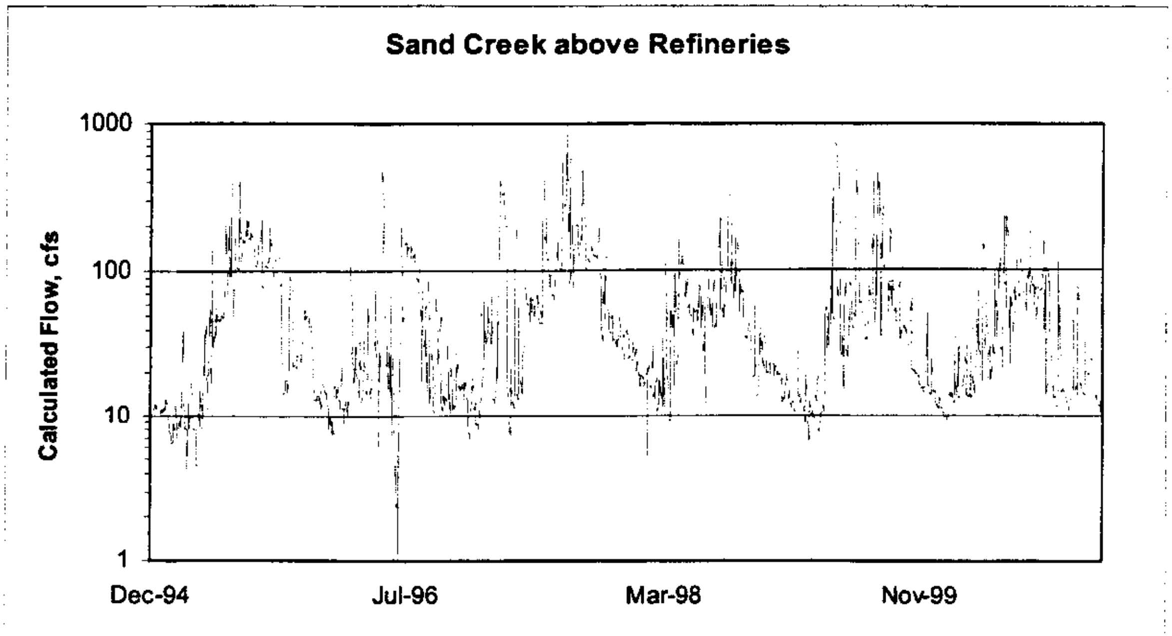


Figure 2. Flow record for the Sand Creek gage. A log scale is used to highlight occurrence of low flows.

zone as defined by Colorado's new mixing zone regulation, as appears to be the case (see below). A low flow of this type was calculated as the sum of source flows (Sand Creek above refineries, South Platte above Cherokee). The result of this method of estimation is shown in Table 2.

Upstream of Sand Creek, the Cherokee power plant receives water from the Farmers and Gardeners Ditch and Copeland Reservoir. Some of this water is used in cooling, during which it is decreased in volume to about 20% of the original amount. The water is pumped from ponds; water use is estimated from pumping records. The discharge, which reflects the processes of power plant cooling and contact with fly ash, passes to holding ponds for settling, is treated in a clarifier, and then is discharged to a channel that leads to the river. A Parshall flume on this channel is the means by which the volume of effluent discharge is estimated.

Some water is routed to the river directly from the supply ponds when they overflow. It is not gaged in any regular way, although it augments the flow near the Cherokee facility; it is mixed with the Cherokee effluent at a point below the effluent measuring Parshall flume and above the confluence of effluent with the South Platte. Estimates were made of the low flows in the South Platte above the Cherokee plant discharge on the basis of gage data for 1992 - 2000 at 64th Avenue and records of the Cherokee plant discharge. For any given day, the recorded flow for the Cherokee effluent outfall was subtracted from the gaged flow at 64th Avenue to yield an estimate of daily flow at a point just above the Cherokee outfall (Figure 3). A DFLOW analysis was then applied to the daily flows. The results are shown in Table 2.

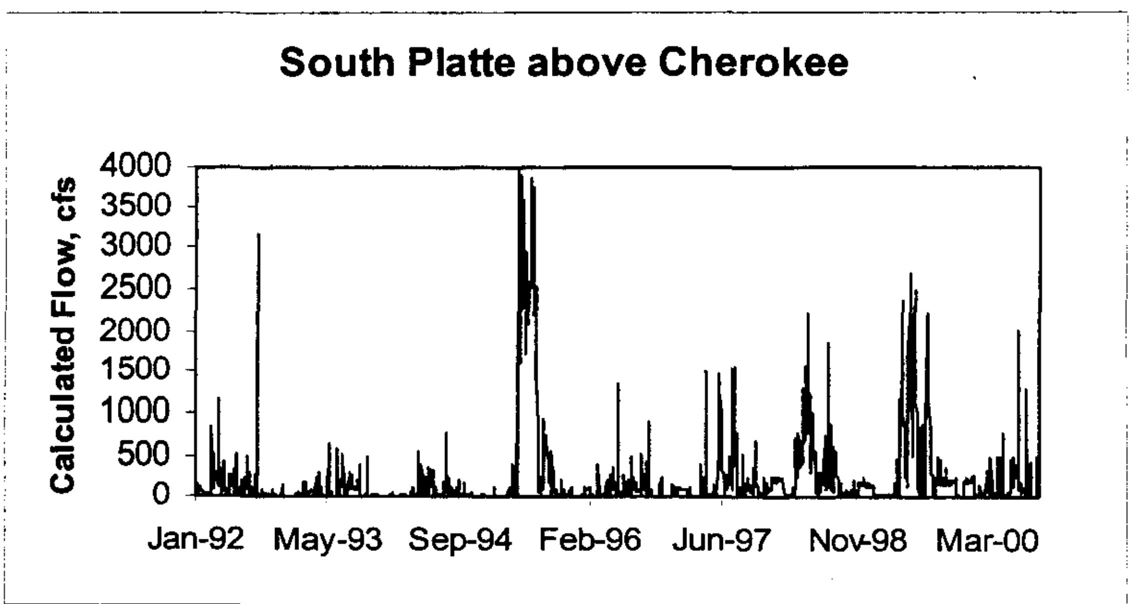


Figure 3. Calculated flow of the South Platte above the Cherokee plant.

The low flows that were obtained from the DFLOW analysis appear to be unrealistically low for the South Platte above Cherokee. This conclusion is based on observation of the site by numerous individuals during dry weather over many years and by the presence of a perennial small flow in this reach that would likely carry at least 1 cfs. Because the DFLOW analysis appears to underestimate the low flows, modelling is based on 1 cfs for acute conditions and 5 cfs for chronic conditions. These low flow values are the ones obtained previously by the CDPHE in its assessment of 12 May 2000, rounded to the nearest whole number.

The assessment modelling requires not only the DFLOW values obtained by direct application of the DFLOW algorithm to daily data for specific locations, but also some calculated low flow values that are internally consistent with each other. The problem of internal consistency arises when two or more source flows are mixed. If separate DFLOW values are obtained for two or more source flows and then simply added together, the result is an underestimate of the appropriate regulatory low flow for the combination of flows. This problem occurs because the DFLOW values for different sources are very unlikely to coincide in time, particularly on the South Platte, where flow regulation is very pronounced.

The solution to internally inconsistent low flows is to obtain by difference an appropriate regulatory low flow for the mixed condition. This method has been used in Segment 15 modelling and is incorporated into the TMDL document for oxygen on Segment 15. For the present assessment, the problem is to obtain an appropriate regulatory low flow for Sand Creek that is consistent with DFLOW condition at the upper end of Segment 15. This is accomplished through a DFLOW analysis on the daily sums of flow for the South Platte above Cherokee and Sand Creek above the refineries. A DFLOW analysis is then performed on these sums. The result is shown in Table 2 ("South Platte Above Cherokee plus Sand Creek Above Refineries"). The DFLOW value for the South Platte above Cherokee is then obtained for the same period of record (1994-2000). The difference between these two values is an internally consistent low flow for Sand Creek above the refineries. This internally consistent low flow above the refineries is listed in Table 2 (next to the last entry in Table 2).

An internally consistent low flow on Sand Creek above the refineries can be used in calculating an appropriate mixed flow for sources plus effluents below Sand Creek on the South Platte Segment 15. For this purpose, the DFLOW value for the South Platte above Cherokee (third entry in Table 2) is added to the internally consistent Sand Creek low flow above the refineries (next to last entry in Table 2), and the capacity flows for all of the effluent sources are then added to this sum. The result is shown in the last line of Table 2.

The appropriate low flow to use in setting limits on Sand Creek depends on the limiting conditions for effluent concentrations. If the limiting conditions for effluent concentrations reaching Sand Creek are determined by their effect on the mixed flow in Segment 15, then the appropriate low flows to be used are those listed as internally consistent (next to the last line in Table 2). If the limiting condition for discharges to Sand Creek is determined by standards that are set on Sand Creek itself, then the DFLOW value should be used in setting effluent limits (second line in Table 2). Whether or not conditions in Sand Creek are limiting may be determined in part by application of the State's new mixing zone regulation (see below).

Mixing Zones

Colorado's new mixing zone regulation states that effluent discharges may, with some exceptions and exclusions, be assigned a regulatory mixing zone equal to six times the square of the bankfull channel width below any given outfall, provided that such mixing zones occupy no more than 10% of river reaches identified on a site-specific basis by CDPHE staff. Exceedance of numeric standards is allowed within a regulatory mixing zone, if CDPHE staff does not disallow or restrict the use of a mixing zone in this manner for a particular site or a particular constituent.

Colorado's mixing zone regulation disallows regulatory mixing zones for discharges that make up more than two-thirds of the combined volume of effluent and receiving water at the point of discharge. Therefore, the Metro District's discharge to South Platte Segment 15 is not affected by a regulatory mixing zone. A regulatory mixing zone is an area within which exceedances are allowed. Full mixing may occur within or beyond the regulatory mixing zone, depending on circumstances.

As shown by Tables 1 and 2, the discharge of the Cherokee power plant qualifies for a regulatory mixing zone because the effluent discharge at capacity is less than double the chronic low flow of the receiving water. The maximum size for the regulatory mixing zone below the Cherokee outfall would be equal to 6 times the square of the bankfull width below the outfall. Field measurements were made of the bankfull channel width by Metro and refinery personnel. The field studies showed a median width of 140.5 feet (14 measurements) between the Cherokee outfall and the Metro bridge. Assuming a more or less triangular mixing zone below the Cherokee discharge, any stream width at low flow less than 95 feet would be consistent with extension of the regulatory mixing zone downstream to the point of the Metro District's outfall ($2 \times 6 \times 140.5^2/2500$). Measurements of the stream width at low flow are not available, but it is unlikely that the width of the South Platte Segment 15 in this reach at low flow would exceed 72 feet. Thus, the limiting factor for the Cherokee discharge would be the influence of the discharge on compliance with standards at the point of mixing with the Metro effluent, rather than over the interval between the Cherokee discharge and the Metro discharge. A hypothetical mixed value must be computed for the South Platte above Metro, however, and compared with the stream standard for location, as an assurance that any exceedance within the regulatory mixing zone are not excessively high. A hypothetically mixed flow (actual mixing may not occur, but no field study has been done of this) could be allowed to have concentrations that exceed the standard because exceedances are allowed in an area equal to the size of the regulatory mixing zone, but this issue needs to be resolved by WQCD.

A mixing zone also applies to lower Sand Creek. The bankfull channel width was studied by Metro and refinery personnel on 13 April 2001. The study showed that the median width of the bankfull channel between the CRC outfall and the Conoco outfalls (2100 feet) was 80.5 feet (25 measurements). Below Conoco and extending down to the Burlington siphon (2300 feet), the median bankfull width was 90 feet (11 measurements). For present purposes, assuming that the relevant width is 80.5 feet, a low flow stream width equal to or less than 18 feet is consistent with extension of a regulatory mixing zone to the mouth of Sand Creek, if the mixing zone is roughly triangular in shape ($2 \times 6 \times 80.5^2/4400$). It is unlikely that the width of Sand Creek exceeds 18 feet at low flow, although measurements are not presently available. Therefore, exceedance of numeric standards can occur in the lower portion of Sand Creek. The limiting factors for refinery discharges to Sand Creek are set by water quality standards for South Platte Segment 15. As in the case of the South Platte above Metro, however, a comparison of hypothetically mixed flow with stream standards at the mouth of Sand Creek should be consistent with stream standards applicable to Sand Creek, even though exceedances are allowed in the regulatory mixing zone.

Because of the presence of mixing zones below the refinery discharges on Sand Creek and below the Cherokee outfall, the overall limiting factor for all discharges is the quality of water at the point below Metro on the South Platte where all discharges are mixed. For the point of mixing of all effluents, the low flows of Sand Creek are those calculated for internal consistency with the low flow in the main stem (see Table 2).

Hardness

Hardness is important to the estimation of appropriate permit limits because hardness controls the standards for a number of metals (the new hardness-based equations effective March 20, 2001, were used in all cases). Useful hardness data are available for the mouth of Sand Creek, the South Platte at 64th Avenue, and the north and south outfalls of the Metro District's effluent. Some data also are available for the South Platte above Cherokee on Sand Creek above the refineries and for the refinery discharges, including data from SP CURE for Sand Creek below Aurora and hardness data from WET test results for refinery effluents.

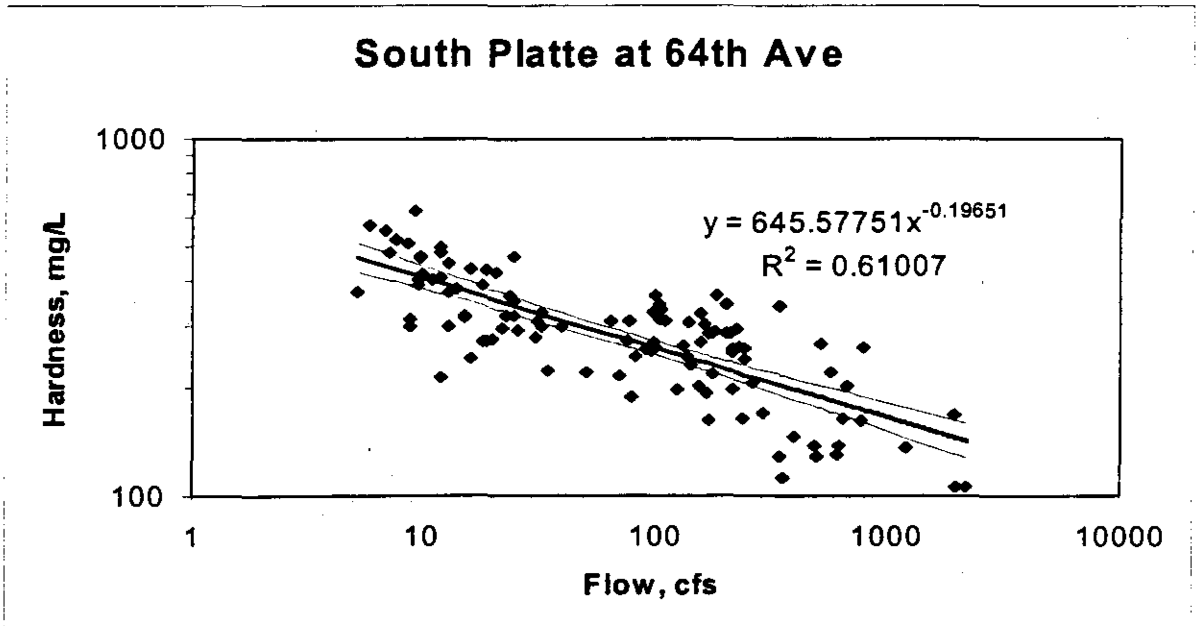


Figure 4. Relationship between flow and hardness for the South Platte at 64th Avenue.

The Colorado Basic Standards require a statistical approach to the estimation of characteristic low-flow hardness for receiving waters, if sufficient data are available. For Sand Creek above the refineries and for the South Platte at 64th Avenue, plots were made of hardness versus discharge (Figures 4, 5). Hardness and discharge were logarithmically transformed for each of these locations because of wide scatter in the data; the transformation resulted in a significant improvement of the relationship between hardness and discharge. For each location, the 95th percentile confidence intervals were determined from the regression of log-transformed data. The lower boundary of the 95 percent confidence interval was then determined for the lowest discharge at which hardness had been measured or the hardness at the low flow used in modelling, whichever was greater. This value, when back transformed, was used as the characteristic low-flow hardness (Table 3).

The characteristic low-flow hardness for the South Platte at 64th Avenue was determined from the 95% confidence interval for the upstream low flow plus effluent discharge at capacity for Cherokee. This hardness was assumed to apply to the Cherokee effluent and to the South Platte above the Cherokee outfall. This assumption, although unavoidable, is not correct; the Cherokee outfall may have a higher hardness than the South Platte above Cherokee. The assumption is conservative for modelling purposes in that any increase in discharge at Cherokee might increase hardness, which would increase the margin of safety for metals whose standards are affected by hardness.

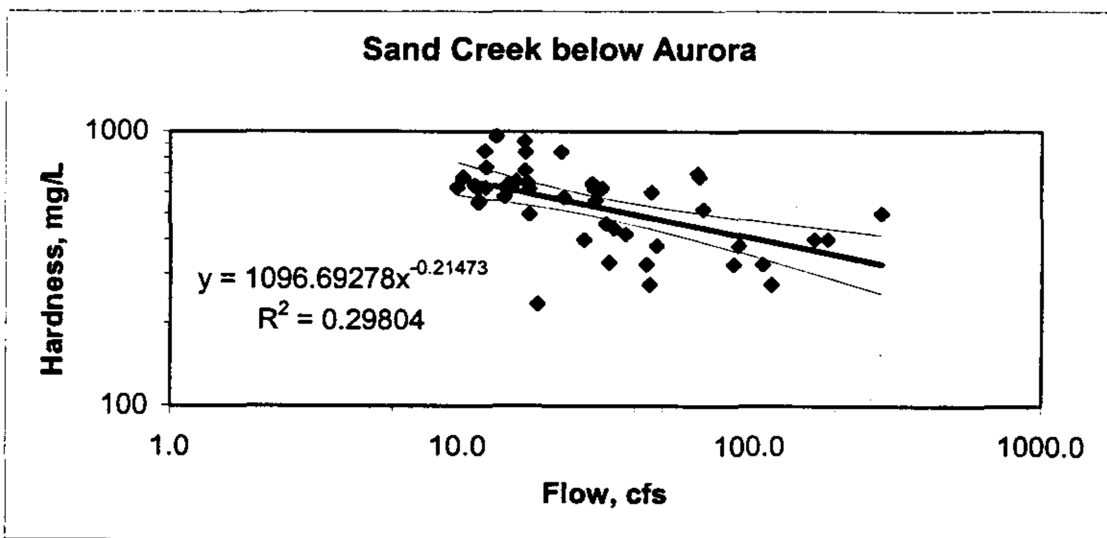


Figure 5. Relationship of flow to hardness on Sand Creek above the refineries.

The calculation of hardness for upstream flow in Sand Creek is the same as for the South Platte above 64th Avenue. The hardness of the refinery discharges was set to the median for values obtained as a byproduct of WET testing (Table 3).

The hardness of the Metro District effluent is well documented. Biweekly values were obtained for both the north and south effluent streams and medians for each of these. The capacity flows for north and south effluent (Appendix A) then were used in calculating a mixed value for hardness at capacity flow in each month. For the annual value, an overall median was calculated.

Conservative Substances

All substances except for ammonia are treated as if they were conservative for purposes of this assessment. Some of these substances, including residual chlorine, hydrogen sulfide, fecal coliforms, and organic substances, are not truly conservative, but the assumption that they are is in itself conservative, insofar as transformational processes involving such substances tend to decrease concentrations.

The conservative substances under consideration for this assessment are listed in Table 4, which is printed directly from the Assessment Model. Table 4 includes information on the concentrations for each constituent in the source water for the South Platte (above Cherokee) and for Sand Creek (above the refineries).

Many of the values in Table 4 were taken from the CDPHE water quality assessment of 12 May 2000 or from SP CURE monitoring programs. Where the values from these sources were given as zero, however, a concentration equal to 10% of the detection limit for the analysis of each substance was added to acknowledge the fact that all the substances are likely to be present at some small concentration, even under background conditions. Also, where no information was available, concentrations were set to 10% of the detection limit, except in the case of mercury, thallium, and sulfide. For these, the standard for one or more locations in the assessment area is so much lower than the detection limit that the source waters were set to 10% of the stream standard.

For the South Platte above Cherokee, field data were available on 10 constituents as a result of field sampling by SP CURE on 8 dates during winter of 2000 (low flow conditions). A median of the concentrations for each of these 10 constituents was used in modelling, as indicated in Table 4.

Cadmium on Sand Creek was a special case because a more extensive data set was available (cadmium study conducted by the City of Aurora through SP CURE). Approximately 30 data points were available, and the median fell below the detection limit, even though there were some measurements showing detection. The data were processed by a statistical technique specifically designed for censored data sets (i.e., data sets containing large numbers of values below detection limits). The method involves construction of a frequency distribution from the values that are above the detection limit for any given constituent, and use of this frequency distribution to estimate a true median for all values, including those that were below the detection limit. The median estimated by this procedure is shown in Table 4.

One special issue that requires some explanation is the reasoning behind the selection of concentrations shown in Table 4 for cadmium in the South Platte. Concentrations of cadmium in the South Platte above Cherokee are very low (<0.3 μg/L). Concentrations of cadmium in effluent from the Cherokee plant also are low (<0.8 μg/L). There is, however, a narrow plume of groundwater entering the South Platte at a point just upstream of the Cherokee discharge and this plume contains very high concentrations of cadmium (2 to 4 μg/L). Consequently, water samples collected at 64th Avenue show much higher concentrations of cadmium than are found either in the South Platte above the groundwater plume or in the Cherokee effluent. For purposes of modelling, this source of cadmium must be acknowledged. For convenience, we treat the additional cadmium from the plume as a component of source water, although in fact it comes in as seepage through the riverbank or bottom. Because remediation of this cadmium source is underway and the Division is evaluating development of a TMDL, the long-term consequences of the plume will be lower than they have been in the past.

Fecal coliform data were treated differently from all other data. Because compliance with standards judged by the calculation of geometric means, geometric means were obtained for samples taken above Cherokee and this mean was used to represent the quality of source water in the South Platte. Because the geometric mean exceeds the standard substantially, the requirement for discharges is assumed to be compliance with the standard at the point of discharge, i.e., there is no assimilative capacity for fecal coliforms in the South Platte.

Table 5 is a summary of the standards that apply to Segment 15 and to Sand Creek. The table excludes the temporary modifications for fecal coliform. The temporary modifications for selenium (Segment 15, 5.2 μg/L chronic; Sand Creek, 12 μg/L chronic; no acute standard on Sand Creek) are handled differently, as these temporary modifications may move either up or down when they are revisited during the next stream standards hearing, and because the temporary modification is subject to a negotiated agreement involving the regulatory agencies.

Standards are shown for Sand Creek, even though these standards might not be strictly applicable because of the existence of a regulatory mixing zone extending to the mouth of Sand Creek below the refinery discharges. Standards also are shown for South Platte Segment 15 between Cherokee and Metro (the standards for numerous substances are different here than below Metro because of the change in hardness caused by the Metro effluent). As in the case of Sand Creek, the standard shown for the portion of Segment 15 between Cherokee and Metro may not be strictly applicable because of the presence of a regulatory mixing zone extending from Cherokee to Metro.

Agricultural standards are shown for Segment 15 (total recoverable iron and manganese) for informational purposes; these standards have not been applied to Segment 15.

Modelling

The assessment model computes mixed values for all constituents of interest at the mouth of Sand Creek, at the South Platte Segment 15 just above Metro, and at the point of full mixing for all 5 effluents on Segment 15 below Sand Creek. For any given constituent, this computation is based on the assumption that all effluent sources will be discharging at capacity (except for the Metro District effluent, which is set at flow expected in the next ten years). The model requires values for effluent limits as components of the mixture. These limits can be set as necessary to bring about compliance with stream standards. Where upstream sources exceed the stream standard, all effluent discharges are set equal to the stream standard.

Setting the effluent limits can be done in a number of different ways, each of which represents a different allocation strategy. For present purposes, it is assumed that the point of compliance for mixed flow is the South Platte Segment 15 below Sand Creek. Segment 15 above Metro and Sand Creek at the mouth are not treated as points of compliance because they are assumed to be encompassed by regulatory mixing zones.

An allocation strategy consistent with these assumptions involves setting Metro's limit equal to the stream standard below Sand Creek, and then setting the limits for Cherokee and the three refinery discharges to a common value that brings the total mixture below Sand Creek up to the standard. One exception is selenium, for which there is a negotiated agreement to the effect that the Metro effluent will be set at 4.6 μg/L and the refinery discharges will be set at 60 μg/L (chronic). The Cherokee effluent, which was not part of the negotiated agreement, was set to 5.2 μg/L, which is the stream standard for chronic exposures. It is anticipated that the Division will decide whether permits need to be reopened for revisions when the final selenium standards are adopted for Segment 15.

Results: Conservative Substances

The results of the assessment modelling are given in Table 6, which shows the acute and chronic limits for all five discharges. Table 6 shows that the limits for the Metro District are more restrictive than the limits for the refineries and for Cherokee in most cases. This is a logical consequence of setting the Metro District's limits equal to the stream standard and allowing the other dischargers to use equally the assimilation capacity that is available when the Metro effluent is required to meet the stream standard at the point of discharge.

The limits shown in Table 6 all are consistent with stream standards on Segment 15 below Sand Creek, with three exceptions. For total recoverable iron and fecal coliforms, the standards are exceeded by the source waters. Thus, even though the dischargers are required to meet the standards at the point of discharge, the mixed flow still would exceed the standard. The third case is selenium, which would exceed the chronic standard by about 0.6 µg/L (the assessment model predicts a mixed concentration of 5.8 µg/L if all dischargers were discharging at permit limits; the temporary modification is for 5.2 µg/L). The acute standard would be exceeded slightly as well. For selenium, the concentrations were not adjusted to achieve balance between the effluent limits and the stream standards because of the existence of a negotiated agreement on selenium concentrations.

Many of the limits listed in Table 6 are more restrictive than limits incorporated in current permits. This tightening of the limits may be a motivation for negotiations among dischargers leading to sharing of assimilation capacity for certain constituents. Such sharing arrangements can be incorporated into modelling once they are worked out through negotiation.

Results: Ammonia

As explained above, ammonia must be dealt with differently than other constituents because the critical conditions for ammonia may occur well downstream of the point of mixing for effluents, and because multiple processes cause large changes in the concentration of unionized ammonia below any point of discharge. For this reason, the Segment 15 water quality model was used in evaluating ammonia limits. The Segment 15 water quality model has been used extensively in permitting and, as applied to oxygen, is the basis of a TMDL on Segment 15.

Conditions for ammonia modelling are summarized in Table 7. The table shows the chronic low flows that are used in the Segment 15 water quality model at the mouth of Sand Creek. These flows differ from the chronic low flows that are derived independently for Sand Creek (as discussed above) because the low flows that are used in the Segment 15 model are internally consistent with each other across the full length of Segment 15. Table 7 also shows the ammonia concentration for the mouth of Sand Creek, which is based on SP CURE monitoring (1998-2000). The total ammonia concentrations have historically been very low, and are conservatively set at 1.0 mg/L (median below detection; one value above 1.0 mg/L).

The low flows and the assumed concentrations lead to the estimation of loads, expressed as kg/d of total ammonia as shown in Table 7.

Table 7 also shows the upstream concentrations (above the refineries on Sand Creek), which is estimated for present purposes as 0.0 mg/L (the median value is below detection for SP CURE samples). Thus the upstream load is 0.0 kg/d, which means that the loads assigned to the mouth of Sand Creek under low flow conditions can be allocated fully among the three discharges. The result of this allocation is shown in the last column of Table 7.

The assumptions inherent in Table 7 could be changed, e.g., by an increase in the assumed concentrations at the mouth of Sand Creek, which would allow greater concentrations from the three refinery discharges. This adjustment, which would require a reduction in concentrations for the Metro District's effluent discharge in order to keep the load in Segment 15 constant, does not appear to be necessary.

Application of the Segment 15 model was for chronic conditions only. The Segment 15 model is not developed yet for acute conditions. Chronic limits typically are most critical for ammonia.

Results: Implications for Sand Creek and Upper Segment 15

Because the allocation strategy was determined entirely on the basis of water quality standards on the South Platte River below Sand Creek, where all of the effluents are mixed together, it is necessary to apply the final result to the other two key locations (mouth of Sand Creek, Segment 15 above Metro) to make sure that substantial exceedances of standards at these key locations do not occur through the use of the allocation strategy. Table 8 lists the constituents that show exceedance of standards according to the allocation strategy that is represented in Table 6. For Sand Creek, exceedances occur for total recoverable iron and for selenium (acute and chronic). The exceedance for total recoverable iron is caused by upstream conditions rather than by the effluent discharges; the effluent discharges are required to meet the standard at the point of discharge. The exceedance for coliforms at the mouth of Sand Creek is caused by high concentrations of fecal coliforms above the effluent discharges (284 organisms per 100 mL, geometric mean). For selenium, exceedances are explained by the negotiated agreement (authorized by CDPHE) that fixes the limits on selenium concentrations for the refineries (60 μg/L) and for Metro (4.6 μg/L). For mercury, exceedances are a byproduct of differing standards for the South Platte and Sand Creek; Sand Creek has standards based on fish consumption.

Table 8 shows a number of exceedances for hypothetically mixed flow below Cherokee and above Metro. These exceedances are a byproduct of the allocation strategy, which calls for Cherokee limits to be set equal to those for the refineries. The exceedances may not be of concern because of the presence of a mixing zone extending from Cherokee down to Metro, and because the magnitude of the exceedances is generally low.

Basis for Permitting

The CDPHE Water Quality Control Division will make decisions regarding permits with reference to the assessment information given above. It is not possible to anticipate exactly how these decisions will be made, but some likely possibilities and principles are as follows.

Limits Based on Conditions in Segment 15 Below Sand Creek

The first requirement for effluent limits of any individual discharger is that these limits be based on firm assumptions about the allowable limits for all other dischargers such that the mixed flow below Sand Creek on Segment 15 of the South Platte River meets the water quality standards for Segment 15, except in the two cases where source waters exceed standards (fecal coliform, total recoverable iron). For the allocation strategy that is outlined in this assessment document, the relevant effluent limits are given by Table 6 for all five discharges. Alternate allocation schemes are possible if a discharger is willing to accept a more stringent effluent limit as a means of creating assimilative capacity that can be used by another discharger. In such a case, the assessment model should be used to find the exact balance of effluent limits under a revised allocation scheme that would be consistent with compliance for the mixed flow in Segment 15 below Sand Creek. A revised allocation scheme would result in a table with the same format as Table 6 but with differing effluent limits for substances that are subject to reallocation.

Lower Sand Creek

From the Division's point of view, it is important to know whether or not Sand Creek becomes fully mixed prior to reaching the South Platte River. Even if the regulatory mixing zone extends to the mouth of Sand Creek, as may be the case, actual mixing of the stream above the confluence with the South Platte likely could cause the Division to cap effluent limits based on the mixture of low flow and effluent within Sand Creek, if such limits were more restrictive than the ones imposed as a result of the need for compliance on the South Platte below Sand Creek. No mixing zone study has demonstrated whether or not full mixing occurs.

The assessment modelling included identification of standards for Sand Creek that would be exceeded if the effluent limits for the refineries were set according to requirements of Segment 15 mixed flow rather than standards applicable to Sand Creek (Table 8). The first two of these standards are total recoverable iron and fecal coliforms. Exceedance of these standards in Sand Creek is unavoidable because the background conditions are above standard. Therefore, the appropriate effluent limit for the dischargers is equal to the standard and there is no need for any special consideration of mixing or other factors.

The acute and chronic mercury standards also are exceeded in Sand Creek if the dischargers are limited by the requirements for the South Platte main stem. The predicted exceedance for acute mercury concentrations is trivial, however, in that it is less than 1% and therefore is not a likely cause for additional restrictions on effluent limits. For mercury under chronic conditions, there is a large discrepancy between the standard and the predicted value if limits for the refinery discharges are set according to requirements for the main stem. This discrepancy is explained by the fact that the main stem standard is for protection of aquatic life and Sand Creek is protected for fish consumption. There are a couple of possibilities for dealing with this discrepancy, and these need to be worked through by the dischargers under review from CDPHE. Given that consumption of fish from Sand Creek is extremely unlikely, the dischargers could request and provide justification for a change in the standard to reflect the protection of aquatic life rather fish consumption. This would require a series of steps under direction from WQCD. A second possibility is that the dischargers might choose to accept a permit limit near 0.01 μg/L, on grounds that mercury has not been detected and probably will not be detected in their effluent (the standard is far below the detection limit).

Another standard at issue for lower Sand Creek is selenium. Selenium is unusual in its treatment by this assessment in that the effluent limits were set according to predetermined concentrations that are incorporated into a negotiated agreement involving the dischargers and WQCD. The concentrations represented in this negotiated agreement lead to an exceedance of the chronic standard for selenium in lower Sand Creek (Table 8). Because of the existence of the negotiated agreement, however, the adjustment of effluent limits for permitting purposes is unlikely. The situation may change, however, when selenium standards are revisited by the State.

The listings in Table 8 for Sand Creek are based on modelling conditions for compliance in the main stem, which means that the low flows for Sand Creek were assumed to be equal to those consistent with low flow in the main stem. These low flows were obtained by difference (DFLOW in the main stem below Sand Creek minus

DFLOW in the main stem above Sand Creek) rather than direct application of the DFLOW algorithm to flows at the mouth of Sand Creek. If the Division wished to view Sand Creek in isolation from the main stem, a stricter approach would be to compute DFLOW values for Sand Creek itself, determine which standard would be exceeded if the effluent limits were as specified in Table 6, and then adjust the limits for these substances downward until compliance is achieved in Sand Creek. Table 9 summarizes the results of such a set of calculations.

Table 9 indicates exceedances for the five standards already mentioned. In addition, however, Table 9 lists aluminum, chromium VI, and residual chlorine. The expected exceedances by use of the stricter approach for calculating low flows are small. The effluent limits for the Sand Creek dischargers can be reduced slightly from those of Table 6 to bring Sand Creek into compliance with the stricter assumptions for low flows in Sand Creek. These adjusted effluent limits are listed in Table 9.

Downward adjustment of the Sand Creek effluent limits for the Sand Creek dischargers results in additional assimilative capacity in the main stem. Because of the small size of the downward adjustments, however, and the small amount of flow of Sand Creek relative to Metro's flow, additional assimilative capacity created in this way is negligible and need not be factored into effluent limits for Metro.

Separate calculations were made for ammonia because of the dependence of unionized ammonia concentrations on pH and temperature, as mentioned in an earlier section of this report. Table 10 shows the results of ammonia effluent limits calculated independently for Sand Creek by use of characteristic monthly pH and temperature values derived from monitoring on Sand Creek. The values in Table 10 can be compared with those in Table 7, which are based on compliance with the ammonia standard in

Segment 15. As shown by the tables, effluent limits are generally more restrictive for compliance with standards in Segment 15 than for compliance with standards for Sand Creek. June, July, and August are exceptional, however, in that the limits derived specifically for Sand Creek would in these months be more restrictive than the limits derived for compliance with standards for Segment 15.

The Xcel Cherokee Discharge

The proximity of the Xcel Cherokee discharge to the Metro discharge and the width of the South Platte River over this reach indicate that full mixing of the Cherokee discharge with the receiving water is unlikely, even at low flow. Therefore, even in the absence of a site-specific study, it seems reasonable to assume that limits for Cherokee can be set on the basis of requirements for compliance with standards at the point of full mixing for all effluents below Sand Creek. If this is the case, restrictions on the Cherokee effluent will be set on the basis of criteria used in establishing Table 6, or any modification of Table 6 based on reallocation, and not on the basis of conditions that prevail on the South Platte between the Cherokee discharge and the Metro discharge.

Overview

In overview, Table 6 could be a reasonable basis for permitting all discharges under current conditions. Table 6 also could be modified for purposes of reallocating assimilative capacity subject to the same constraints that were used in the present version of Table 6. Table 9 can be used as an overriding supplement to Table 6 if the Division decides to treat Sand Creek separately from the main stem.

Discharge	Permit Number	Capacity (mgd)	Capacity (cfs)
Discharges of Primary Concern for this Assessment			
Cherokee Power Plant	0001104	5.5	8.5
Metro District[1]	0026638	170.6	264
CRC Process[2]	0001210	0.50	0.77
Conoco Process[2]	0001147(002)	0.82	1.27
Conoco Groundwater	0001147(003)	2.16	3.34
Discharges of Secondary Concern for this Assessment			
Brighton		4.5	7.0
South Adams		7.0	10.8
Aurora		5.0	7.7

[1] Includes 76.8 mgd south complex, 93.8 mgd north complex (both averages of monthly values used in the Segment 15 water quality model).
[2] Includes provisions for intermittent hydrostatic testing (not considered relevant for modelling).

Table 1. Discharges relevant to the assessment.

Location	Source	Acute cfs	Chronic cfs	Years
DFLOW Values				
Sand Creek Above Refineries	CDPHE[1]	2.9	8.6	1992-1998
Sand Creek Above Refineries[3]	This Study	3.5	10.2	1994-2000
South Platte Above Cherokee[3]	CDPHE[2]	0.9	5.4	
South Platte Above Cherokee	This Study	0.0	2.2	1992-2000
Internally Consistent Low Flows				
South Platte Above Cherokee Plus Sand Creek above Refineries		14.2	23.4	1994-2000
South Platte Above Cherokee		2.2	7.8	1994-2000
Sand Creek Above Refineries[3]		12.0	15.6	1994-2000
South Platte Below Sand Creek[3]		291	299	By Difference

[1] CDPHE Water Quality Assessment, 12 May 2000.
[2] Xcel Cherokee plant NPDES permit.
[3] Used in modelling (Platte values rounded to nearest cfs; see text).

Table 2. Annual low flows (1E3, 30E3) used in this study and low flows for the same locations used previously for assessment or permitting.

Location	Hardness, mg/L		Method
	Acute	Chronic	
Source Flows and Effluents			
South Platte at 64th	384	362	Regression, 95% C.I.
South Platte Above Cherokee	384	362	Set Equal to Platte at 64th
Cherokee Effluent	384	362	Set Equal to Platte at 64th
Sand Creek Above Refineries	569	545	Regression, 95% C.I.
CRC	162	162	Median
Conoco 002	198	198	Median
Conoco 003	420	420	Median
Metro District	179	179	Median[1]
Mixed Flows[2]			
Mouth of Sand Creek	495	490	Flow Weighted Mix
South Platte blw Sand Creek	210	205	Flow Weighted Mix

[1]Flow-weighted mix of median hardness in north (174) and south (186) complexes.
[2]Hardness values above 400 mg/L for mixed flows were capped at 400 mg/L when used in hardness-based equations.

Table 3. Summary of hardness values used in modelling.

Constituent (diss.unless noted)	South Platte Conc., µg/L	Source	Sand Creek Conc., µg/L	Source	Det. Lim., µg/L	Notes
Aluminum	10[1]	No Data	10[1]	No Data	100	Metro Lab Services
Antimony	0.5[1]	No Data	0.5[1]	No Data	5	Metro Lab Services
Arsenic	1.0[2]	SP CURE	1[2]	CDPHE	10	Metro Lab Services
Barium	5[1]	No Data	5[1]	No Data	50	Metro Lab Services
Beryllium	2[1]	No Data	2[1]	No Data	20	Metro Lab Services
Cadmium	4	SP CURE	0.00075[7]	SP CURE	0.1	Metro Lab Services
Chromium VI	0.5[2]	SP CURE	0.5[2]	CDPHE	5	Metro Lab Services
Copper	3.5	SP CURE	3.5	SP CURE	1	Metro Lab Services
Iron (Trec)	110[3]	CDPHE	1990	CDPHE	50	Metro Lab Services
Iron (dis)	110	SP CURE	160	SP CURE	50	Metro Lab Services
Lead	1.0[2]	SP CURE	3.1	SP CURE	10	Metro Lab Services
Manganese (dis)	215	SP CURE	152	SP CURE	20	Metro Lab Services
Mercury	0.02[2]	CDPHE	0.001[5]	CDPHE	0.2	Metro Lab Services
Nickel	2.0[2]	SP CURE	2[2]	CDPHE	20	Metro Lab Services
Selenium	2.0[4]	CDPHE	9.2	SP CURE	2	Metro Lab Services
Silver	0.02[2]	CDPHE	0.018	SP CURE	0.2	Metro Lab Services
Thallium	0.05[5]	SP CURE	0.6[1]	No Data	6	Metro Lab Services
Uranium	0.1[1]	No Data	0.1[1]	No Data	1[9]	Standard Methods
Zinc	30	SP CURE	17.2	SP CURE	0.3	Metro Lab Services
Benzene	0.04[2]	CDPHE	0.1[2]	CDPHE	.4 to 1.0	CDPHE WQ Assessmt.
1,1,1-Trichloroethane	0.5[1]	No Data	0.5[1]	No Data	5	Metro Lab Services
Fecal Coliforms	306	Metro	284	Metro		
Residual Chlorine	5.0[1]	No Data	5[1]	No Data	50	Metro Lab Services
Sulfide as H2S	0.2[5]	No Data	0.2[5]	No Data	5	Metro Lab Services
Manganese (Trec)	215[6]	CDPHE	152[8]	CDPHE	20	Metro Lab Services

Table 4. Upstream concentrations for three key locations. Footnotes appear in Appendix B.

	Location					
	Segment 15 Below Cherokee[1]		Sand Creek Mouth		Segment 15 Below Sand Creek	
Constituent	Acute	Chronic	Acute	Chronic	Acute	Chronic
Aluminum	750	87	750	87	750	87
Antimony	-	-	-	-	-	6.0
Arsenic	50	-	-	100	50	-
Barium	-	-	-	-	1000	490
Beryllium	-	100	-	100	-	4.0
Cadmium	18.3	5.8	19.1	6.1	9.3	3.9
Chromium (VI)	16	11	16	11	16	11
Copper	48	27	50	29	26	17
Iron (Tot. rec.)	-	1000	-	1000	-	1000
Iron (Diss.)	-	300	-	-	-	300
Lead	269	10	281	11	140	6
Manganese (Tot. rec.)	-	200	-	200	-	200
Manganese (Diss.)	4674	400	4738	2618	3792	400
Mercury	2.40	0.40	1.40	0.01	2.40	0.40
Nickel	163	155	169	168	96	97
Selenium[3]	18.4	5.2	-	12	18.4	5.2
Silver	20.5	2.9	22.0	3.5	7.0	1.1
Thallium	-	15.0	-	15.0	-	0.5
Uranium	10583	6194	11070	6915	5298	3390
Zinc	366	350	379	381	215	220
Benzene	5300	-	5300	-	5300	1.2
TCE	-	-	-	-	-	200
Fecal Coliforms[2]	200	-	200	-	200	-
Residual Chlorine	19	11	19	11	19	11
Sulfide as H_2S	-	2.0	-	2.0	-	2.0

[1]Standards for drinking water supply may not be relevant to Segment 15 upstream of the Metro discharge because there is no diversion for drinking water supply on Segment 15 upstream of Metro.
[2]Given as number per 100 ml.
[3]Values shown are temporary modifications.

Table 5. Standards for the key locations in the assessment (all except coliforms are given as μg/L). Standards for Segment 15 below Cherokee were used in calculating effluent limits shown in Table 6.

		Acute Limit, µg/L					Chronic Limit, µg/L				
Constituent	Offset	Cherokee	CRC	Conoco 2	Conoco 3	Metro	Cherokee	CRC	Conoco 2	Conoco 3	Metro
Aluminum	1	1425	1425	1425	1425	750	200	200	200	200	87
Antimony	2	-	-	-	-	-	14	14	14	14	6
Arsenic	3	95	95	95	95	50	-	-	-	-	-
Barium	4	1900	1900	1900	1900	1000	1200	1200	1200	1200	490
Beryllium	5	-	-	-	-	-	6.9	6.9	6.9	6.9	4
Cadmium	6	17.6	17.6	17.6	17.6	9.3	8.0	8.0	8.1	8.1	3.9
Chromium VI	7	30	30	30	30	16	26	26	26	26	11
Copper	8	47	47	47	47	26.4	36.5	36.5	36.5	36.5	16.9
Iron (Trec)[1]	9	-	-	-	-	-	1000	1000	1000	1000	1000
Iron (dis)	10	-	-	-	-	-	520	520	520	520	300
Lead	11	267	267	267	267	140	9.9	9.9	9.9	9.9	5.6
Manganese (dis)	12	7150	7150	7150	7150	3792	745	745	745	745	400
Mercury	13	4.6	4.6	4.6	4.6	2.4	0.98	0.98	0.98	0.98	0.4
Nickel	14	183	183	183	183	96	239	239	239	239	96
Selenium[1,2]	15	18.4	60	60	60	18.4	5.2	60	60	60	4.6
Silver	16	13.4	13.4	13.4	13.4	7.0	2.8	2.8	2.8	2.8	1.1
Thallium	17	-	-	-	-	-	0.5	0.5	0.5	0.5	0.5
Uranium	18	10000	10000	10000	10000	5298	8400	8400	8400	8400	3390
Zinc	19	395	395	395	395	215	510	510	510	510	220
Benzene	20	10000	10000	10000	10000	5300	2.8	2.8	2.8	2.8	2.8
TCE	21	-	-	-	-	-	490	490	490	490	200
Fecal Coliforms[2]	22	200	200	200	200	200	-	-	-	-	-
Residual Chlorine	23	32	32	32	32	19	19	19	19	19	11
Sulfide as H2S	24	-	-	-	-	-	4.4	4.4	4.4	4.4	2
Manganese (Trec)	25	-	-	-	-	-	240	240	240	240	200

[1]Chronic standard exceeded.

[2]Acute standard exceeded; fecal coliform shown as cells per 100 ml.

Table 6. Effluent limits consistent with standards, except as noted. See text for allocation rationale. Acute < chronic for nickel (not an error; inherent in new standards). Selenium is evaluated on the basis of temporary modifications.

	Sand Creek at Mouth			Sand Creek above Refineries			Refineries, mg/L
	Low Flow, cfs Chronic	Concentration, mg/L	Load, kg/d Chronic	Low Flow, cfs Chronic	Concentration, mg/L	Load, kg/d Chronic	
Jan	13.0	1.0	31.8	11.0	0.00	0.0	2.4
Feb	12.9	1.0	31.6	11.0	0.00	0.0	2.4
Mar	13.0	1.0	31.8	11.0	0.00	0.0	2.4
Apr	16.6	1.0	40.6	12.0	0.00	0.0	3.1
May	29.4	1.0	71.9	13.0	0.00	0.0	5.5
Jun	34.7	1.0	84.9	9.3	0.00	0.0	6.4
Jul	43.0	1.0	105.2	9.3	0.00	0.0	8.0
Aug	31.0	1.0	76.1	15.0	0.00	0.0	5.8
Sep	20.1	1.0	49.2	18.0	0.00	0.0	3.7
Oct	19.8	1.0	48.4	15.0	0.00	0.0	3.7
Nov	13.9	1.0	34.0	14.0	0.00	0.0	2.6
Dec	13.4	1.0	32.8	11.0	0.00	0.0	2.5

Table 7. Allocation to the refineries for total ammonia developed through use of the Segment 15 water quality model (see text for explanation).

Constituent	Predicted[1] µg/L	Standard µg/L
Mouth of Sand Creek[2]		
Iron (tot. rec.) Chronic	1736	1000
Mercury Acute	1.4[3]	1.4
Mercury Chronic	0.25	0.01
Selenium Chronic[4]	20.2	12
Fecal Coliform	258	200
South Platte between Cherokee and Metro[5]		
Aluminum Acute	1276	750
Aluminum Chronic	130	87
Arsenic Acute	85	50
Cadmium Chronic	6.6	5.8
Chromium Acute	27	16
Chromium Chronic	17	11
Iron (dis) Chronic	368	300
Manganese (dis) Acute	6421	4674
Manganese (dis) Chronic	549	400
Mercury Acute	41	2.4
Mercury Chronic	0.6	0.4
Nickel Acute	164	163
Benzene Acute	8948	5300
Fecal Coliforms Acute	211	200
Residual Chlorine Acute	29	19
Residual Chlorine Chronic	14	11
Sulfide Chronic	2.8	2.0
Manganese (Trec) Chronic	231	200

[1]Assuming 100% mix, with effluent characteristics as shown in Table 6.
[2]Low flow for Sand Creek set to difference of low flow downstream and low flow upstream.
[3]Slightly exceeds 1.4.
[4]Acute not shown because temporary modification shows no acute limit; predicted value would be 24.9 µg/L.
[5]Standards for drinking water supply may not be relevant to Segment 15 upstream of the Metro discharge because there is no diversion for drinking water supply on Segment 15 upstream of Metro.

Table 8. Exceedances for hypothetically mixed flow at the locations where regulatory mixing zones are located, assuming all discharges are at capacity and reaching concentration limits shown in Table 6 (given as µg/L).

Constituent	Predicted[1] µg/L	Standard µg/L	Revised Effluent Limit[2], µg/L
Aluminum (Acute)	868	750	1230
Chromium VI (Acute)	18.4	16	26
Iron (Trec, Chronic)	1648	1000	N/A[3]
Mercury (Acute)	2.8	1.4	2.3
Mercury (Chronic)	0.34	0.01	0.027[4]
Selenium (Chronic)	26.8	12	N/A[5]
Benzene (Acute)	6060	5300	8740
Fecal Coliform (Acute, cells/100mL)	233	200	N/A[3]
Residual Chlorine (Acute)	21.4	19	28

[1]Predicted with effluent limit as shown in Table 6.
[2]As necessary to meet standard with Sand Creek treated independently.
[3]No revision; source exceeds standard, use Table 6.
[4]Standard probably inappropriate.
[5]Limit set by negotiated agreement (60µg/L).

Table 9. Exceedances that would occur in Sand Creek with refinery effluent limits as shown in Table 6 but with stricter low flow assumptions (independent low flow analysis for Sand Creek). Effluent limits needed to eliminate exceedances under these stricter conditions are shown in the last column.

Month	Acute		Chronic
January	13.3	*	14.9
February	11.0	*	13.9
March	7.7		6.7
April	12.3		10.1
May	11.3		8.6
June	7.0		3.6
July	5.8		2.7
August	12.4		4.3
September	5.7		5.2
October	8.4		5.4
November	7.9		5.9
December	6.6	*	8.0

* Acute < chronic; use acute for chronic limit.

Table 10. Monthly effluent limits for total ammonia (mg/L as N) in refinery discharges to Sand Creek consistent with ammonia standards on Sand Creek.

Appendix A

Monthly Characteristics of the Metro Discharge

Month	SFE	NFE	Total
January	71	84	155
February	71	83	154
March	73	85	158
April	74	93	167
May	82	101	183
June	84	101	185
July	83	101	184
August	84	101	185
September	78	101	179
October	74	97	171
November	74	92	166
December	74	86	160
Average	77	94	171

A1. Flows (mgd) for Metro District discharge, as used in modelling for the assessment.

Month	SFE Median	NFE Median
January	182.0	164.5
February	179.0	158.0
March	180.0	168.5
April	193.0	189.0
May	197.5	193.0
June	196.5	191.0
July	193.5	171.0
August	196.0	189.0
September	183.5	167.0
October	183.5	182.0
November	192.0	185.0
December	171.5	161.0
Annual	186.0	174.0

A2. Hardness data (mg/L) for Metro District discharge, as used in modelling for the assessment.

Appendix B

Footnotes to Table 4

Footnote 1. No data; set concentration equal to factor times detection limit.

Footnote 2. Measured values less than detection limits; set concentration equal to factor times detection.

Footnote 3. Median value in CDPHE report was 58; replaced with median dissolved concentration which is higher.

Footnote 4. as Trec.

Footnote 5. Ambient set to 10% of stream standard.

Footnote 6. Median value in CDPHE report was 116; replaced with median dissolved concentration, which is higher.

Footnote 7. Median estimated from censored data set by log probability plot procedure.

Footnote 8. Median value in CDPHE report was 30; replaced by median dissolved concentration, whish is higher.

Footnote 9. Detection limit is set arbitrarily. IDL of U238 is 0.001 μg/L by ICP/MS. U238 is 99% of element present. Stream standards are 3-4 orders of magnitude higher.

TOTAL MAXIMUM DAILY LOAD ASSESSMENT

DISSOLVED OXYGEN

SOUTH PLATTE RIVER – SEGMENT 15
BURLINGTON DITCH TO BIG DRY CREEK
ADAMS and WELD COUNTIES, COLORADO
Public Notice Draft – February 25, 2000

TMDL SUMMARY

Waterbody Name/Segment Number	Main stem of the South Platte River from the Burlington Ditch Headgate to the confluence with Big Dry Creek COSPUS15
Pollutant/Condition Addressed	Dissolved Oxygen (for protection of aquatic life)
Affected Portion of Segment	All of the segment is evaluated
Use Classification/Waterbody Designation	Aquatic Life (Warm Water Class II) Recreation (Class II), Drinking Water , Agriculture
Waterbody Designation	Use Protected
Water Quality Target	Increase concentrations of dissolved oxygen in the stream through a combination of pollutant controls (primarily on ammonia discharge) and localized, physical improvements in the river channel
TMDL Goal	Achieve compliance with the Segment 15 dissolved oxygen standards

I. EXECUTIVE SUMMARY

To assure meeting dissolved oxygen standards for Segment 15 of the South Platte River, this TMDL establishes requirements for ammonia discharge permit limits and requirements for physical improvements in the river channel. Implementation of these requirements will be through discharge permits for point source discharges. Non-point sources and storm water discharges are not significant contributors to dissolved oxygen suppression and are not regulated under this TMDL. The TMDL will assure the dissolved oxygen standards will be met even if the maximum amount of ammonia allowed by permit limits is discharged. Because the size of discharges is expected to change in the future and because of potential changes in the river, continued monitoring is needed. This TMDL should be reviewed at least every five years and revised whenever appropriate.

II. INTRODUCTION

Section 303(d) of the federal Clean Water Act requires states to identify water bodies or stream segments that do not meet water quality standards. For Colorado, these waters currently are identified in the state's 1998 303(d) list. Water quality limited segments are those water bodies or stream segments which, for one or more assigned use classifications or standards, the classification or standard is not achieved or would not be achieved without effluent controls. Once listed on the 303(d) list, the state is required to develop a Total Maximum Daily Load (TMDL) assessment that describes how the water quality standards can be achieved. The TMDL assessment includes quantification of the amount of a specific pollutant that a listed water body can assimilate without violating applicable water quality standards. The assessment usually apportions the allowable quantity among the pollutant sources. The maximum allowable amount of pollutant is referred to as the Total Maximum Daily Load. The TMDL is comprised of the Load Allocation (LA) which is that portion of the pollutant load attributed to natural background or non-point sources, the Waste Load Allocation (WLA) which is that portion of the pollutant load associated with point source discharges, and a Margin of Safety (MOS). The TMDL also may include an allocation reserved for future growth. The TMDL may be expressed as the sum of the LA, WLA, and MOS. Where there is assurance of implementation, the TMDL may also recognize actions, other than pollutant control, that help achieve standards.

The South Platte River originates in the Rocky Mountains of Colorado at the Continental Divide. It flows out of the foothills and through the Denver metropolitan area and thence northeasterly through Colorado into Nebraska.

Segment 15 (COSPUS15) of the South Platte River was identified on Colorado's 1998 303(d) list as partially impaired for dissolved oxygen. This finding was based on field monitoring and on modeling. Past monitoring data shows that the stream did not meet dissolved oxygen standards. More recent monitoring data suggests that Segment 15 presently complies with

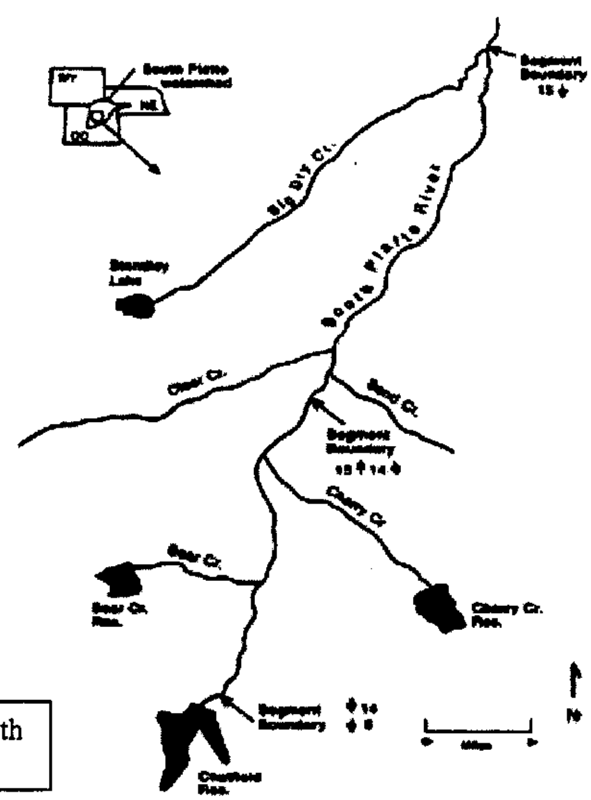


Figure 1. Location of Segment 15 of the South Platte River within Colorado

the aquatic life standard for dissolved oxygen. In fact, the long-term monitoring record shows substantially improved oxygen conditions in Segment 15.

Even though Segment 15 appears to be in compliance with standards for dissolved oxygen at the present time, modeling shows that the segment would not be in compliance if the point source discharges were all running at capacity and all contained total ammonia matching the permit limits. In other words, additional requirements are necessary to assure meeting the dissolved oxygen standards adopted for Segment 15 in the future.

Figure 2. South Platte River in Adams County

Segment 15 of the South Platte River begins in the northern portion of the metropolitan area and flows northward into Weld County. Specifically, the segment begins at the headgate of the Burlington Ditch (near 52nd Avenue and near the border between the City and County of Denver and Adams County) and ends at the confluence with Big Dry Creek in Weld County (about one mile south of the City of Fort Lupton). The Hydrologic Unit Code is 10190003. Figure 3 shows the location of Segment 15 on the South Platte River and important locations along the segment.

Segment 15 is surrounded by a variety of land uses. Segment 14, immediately upstream, is intensely urbanized. The upstream portion of Segment 15 is within the northern part of the metropolitan Denver area and is also urbanized, but less intensively. As the river nears 96th Avenue, it enters a transition from urban open space and agricultural uses with dispersed residential development. Between 64th Avenue and the Weld County line, there are also intensive gravel extraction activities immediately adjacent to the river. As the river passes through the City of Brighton, it passes through a small urban zone and then returns to agricultural land uses further downstream.

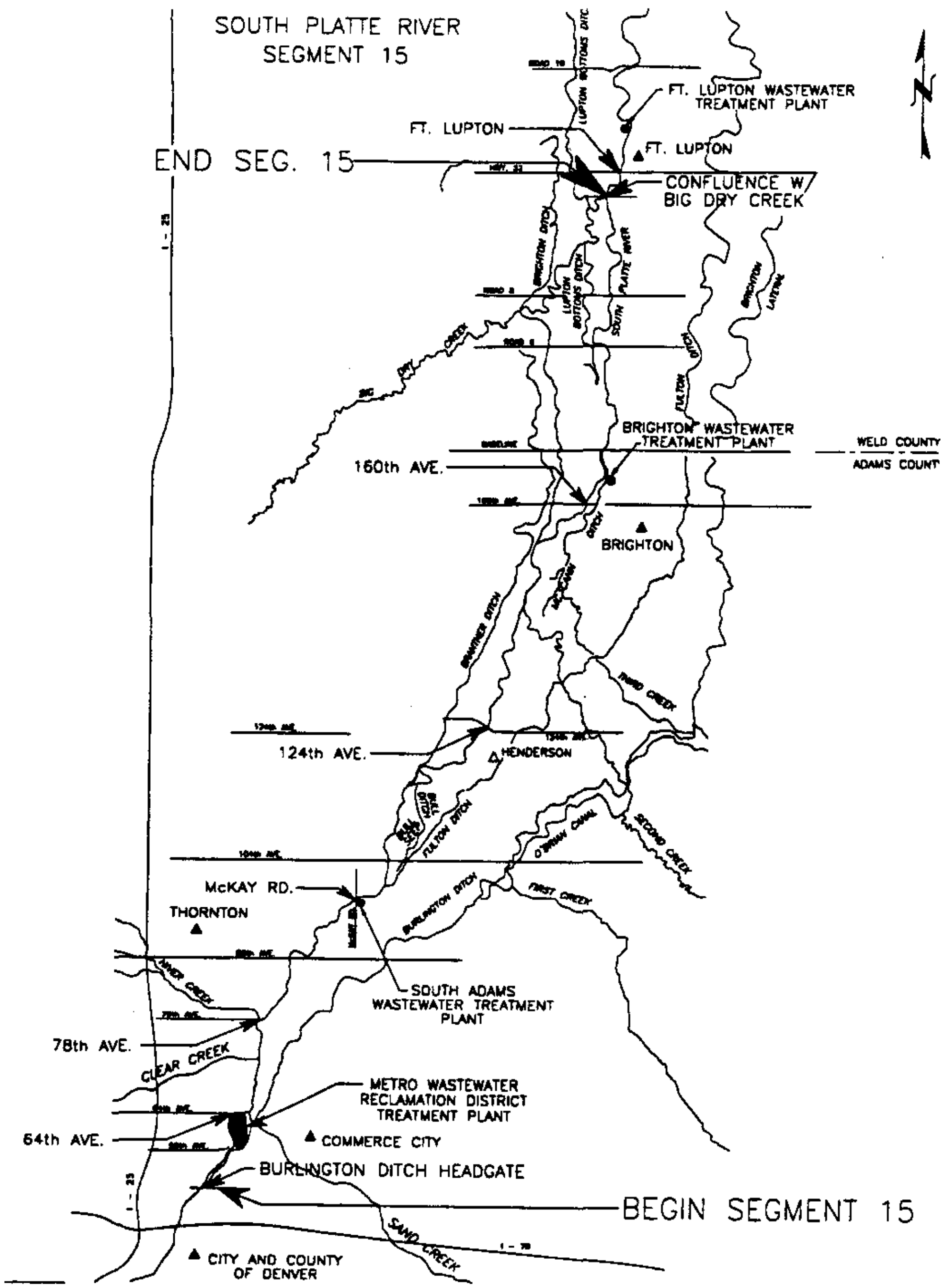


Figure 3. Map of Segment 15 of the South Platte River showing relevant features.

The flow in Segment 15 is largely controlled for agricultural and municipal uses of water. During winter months, the entire upstream flow of the South Platte River is often diverted at the Burlington headgate for agricultural uses in Adams and Weld Counties (Figures 4 and 5).

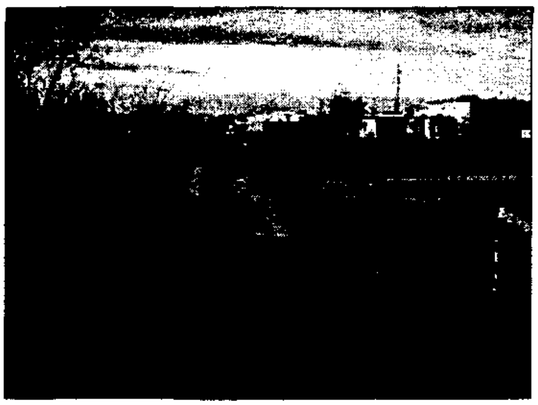


Figure 4. Burlington Ditch headgate.

Figure 5. South Platte River upstream of the Metro District discharge.

At such times, over 90% of the flow in the river comes from wastewater treatment plant discharges, ground water seepage, and very small ungaged tributaries. The largest discharger to Segment 15 is the Metro Wastewater Reclamation District which discharges about two miles downstream of the Burlington headgate (near the confluence of the South Platte River with Sand Creek - Figure 6). The South Adams County Water and Sanitation District and the City of Brighton also discharge treated effluent to the river.

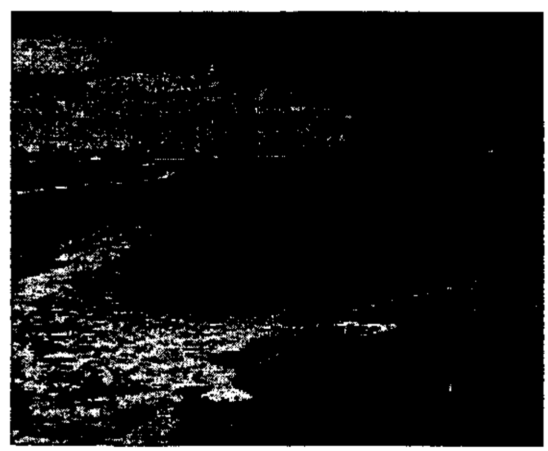


Figure 6. Discharge from the Metro District Wastewater Treatment Plant located about two miles downstream from the Burlington Ditch diversion.

There are two major tributaries to the South Platte in Segment 15: Sand Creek and Clear Creek. Big Dry Creek marks the end of the segment; its discharge does not affect the concentrations of dissolved oxygen in Segment 15. Historically, Sand Creek was an intermittent stream, but recently it has discharged steadily because of urbanization, which has led to increased wastewater discharges and ground water seepage into Sand Creek. Most of the flow in Clear Creek is diverted for municipal and agricultural uses before reaching the confluence with the South Platte River; this is especially true during the fall, winter, and early spring. As there are no major reservoirs along Clear Creek, it exhibits some characteristics of a free-flowing stream during spring snowmelt (i.e., it is not uncommon to have high flows from Clear Creek into the South Platte from May into July). There are also a number of irrigation diversions along Segment 15 (Fulton – Figure 7, Brantner, Brighton, and Lupton Bottoms). These are direct diversion rights and currently operate only during the agricultural irrigation season (April to September).

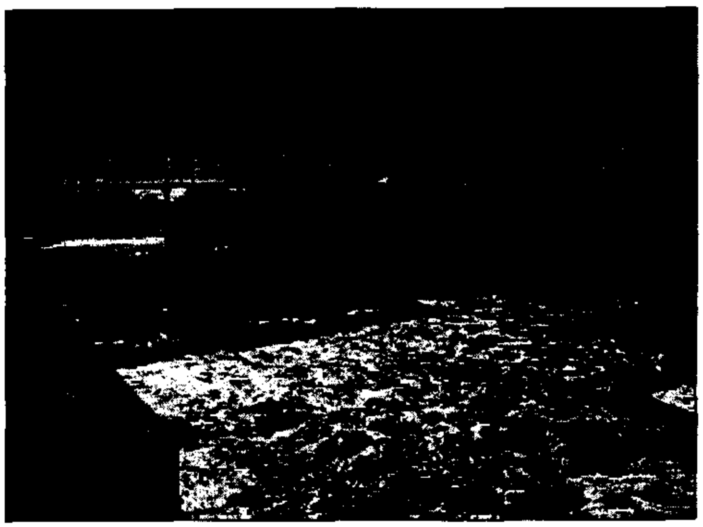


Figure 7. The Fulton Ditch diversion with the gates open and no diversion for irrigation.

Over the next 50 years, much of the land along the downstream section of Segment 15 is expected to urbanize. The flow regime in the river is also likely to change as agricultural uses of water are converted to municipal use. There is potential for increased discharges of effluent to Segment 15 and potential for smaller volumes of water to be carried through Segment 15. Over time, these changes could affect dissolved oxygen in the segment, but the nature of the changes is difficult to predict.

Improvements to raise the dissolved oxygen concentrations in Segment 15 have been underway for a number of years. This TMDL assessment summarizes the ongoing activities and establishes the formal TMDL for dissolved oxygen. Because changes in Segment 15 are likely over time, it is anticipated the TMDL will have to be revised periodically.

III. WATER QUALITY STANDARDS

While a number of uses are assigned to Segment 15 of the South Platte River, Aquatic Life - Warm Water Class 2 is the controlling use classification related to dissolved oxygen. Segment 15 has site-specific dissolved oxygen standards that were adopted by the Colorado Water Quality Control Commission and approved by the U. S. Environmental Protection Agency.

Table 1. Dissolved Oxygen Standards

UPPER SOUTH PLATTE RIVER SEGMENT 15

Site-Specific Minimum Dissolved Oxygen Standards

UNDERLYING STANDARDS

Early Life Stage Protection Period (April 1 through July 31)

1-Day [1,5,6]	3.0 mg/L (acute)
7-Day Average [1,2,4]	5.0 mg/L

Older Life Stage Protection Period (August 1 through March 31)

1-Day [1,5]	2.0 mg/L (acute)
7-Day Mean of Minimums [1,3]	2.5 mg/L
30-Day Average [1,2].	4.5 mg/L

TEMPORARY MODIFICATION

During the period until October 31, 2001, the Segment 15 dissolved oxygen standards from 88th Avenue north to the end of the Segment shall be the currently existing ambient conditions as monitored in 1992, 1993, and 1994 by the Division and by the Metro District. Beginning November 1, 2001, the standards shall apply to all sections of Segment 15 south of the Brighton Ditch diversion. The standards north of the Brighton Ditch diversion shall continue to be the ambient conditions existing in 1992, 1993, and 1994. Beginning November 1, 2004, the standards shall apply to all sections of Segment 15.

Footnotes

1. For the purpose of determining compliance with the standards, dissolved oxygen measurements shall only be taken in the flowing portion of the stream at mid-depth, and at least six inches above the bottom of the channel. All sampling protocols and test procedures shall be in accordance with procedures and protocols approved by the Division.

2. A minimum of four independent daily means must be used to calculate the average for the 7-Day Average standard. A minimum of eight independent daily means must be used to calculate the average for the 30-Day Average standard. The four days and the eight days must be representative of the 7-Day and the 30-Day periods respectively. The daily mean shall be the mean of the daily high and low values. In calculating the mean values, the dissolved oxygen saturation value shall be used in place of any dissolved oxygen measurements which exceed saturation.

3. The 7-Day Mean Minimum is the average of the daily minimums measured at a location on each day during any 7-Day period.

4. North of the Lupton Bottoms Ditch diversion, the ELS 7-Day average standard for the period July 1 - July 31 shall be 4.5 mg/L.

5. During a 24 hour day, dissolved oxygen levels are likely to be lower during the nighttime when there is no photosynthesis. The dissolved oxygen levels should not drop below the acute standard (ELS acute standard of 3.0 mg/L or the OLS standard of 2.0 mg/L). However, if during the ELS period multiple measurements are below 3.0 mg/L during the same nighttime period, the multiple measurements shall be considered a single exceedance of the acute standard. For measurements below 2.0 mg/L during either the ELS or the OLS periods, each hourly measurement below 2.0 mg/L shall be considered an exceedance of the acute standard.

6. In July, the dissolved oxygen level in Segment 15 may be lower than the 3.0 mg/L acute standard for up to 14 exceedances in any one year and up to a total of 21 exceedances in three years before there is a determination that the acute dissolved oxygen standards is not being met. Exceedances shall be counted as described in Footnote 5.

Table 1. Dissolved Oxygen Standards

The dissolved oxygen standards in Table 1 were adopted to protect aquatic species that are present in the river or could be present in the river through a normal life cycle. Because oxygen is a requisite for life rather than a toxin, the standard sets minimum rather than maximum concentrations. The standards include instantaneous minima as well as chronic minima and recognize the need for higher concentrations of dissolved oxygen during periods of the year when protection of early life stages is most important. While the Segment 15 dissolved oxygen standards include temporary modifications, this TMDL is intended to meet the underlying dissolved oxygen standards for Segment 15.

The subject of this TMDL assessment is the dissolved oxygen standards. A nitrate TMDL assessment is being done in parallel with this effort, but is being documented separately, as the issues and control strategies are different. For Segment 15, TMDL assessments also will be done for copper, and cadmium within the next few years.

IV. PROBLEM IDENTIFICATION

In the 1980s, monitoring showed that dissolved oxygen in Segment 15 was suppressed by municipal effluent, especially during times of low flow in the river. Ammonia (NH_3)was identified as the predominant effluent constituent suppressing dissolved oxygen. Ammonia uses oxygen through the natural process of nitrification in the stream, during which ammonia is converted to nitrate. Modeling showed that the Metro Wastewater Reclamation District needed to install nitrification facilities that would reduce ammonia in about half of its effluent. In addition, new facilities were needed to partially denitrify this effluent through the conversion of nitrate to nitrogen gas. These additional treatment facilities were completed and operational by 1991.

During the late 1980s and early 1990s, the Metro District expanded its stream monitoring program so that it would produce more detailed information on processes affecting dissolved oxygen in Segment 15. The Metro District also began the development of a sophisticated water quality model that could be used to assess the best ways to increase concentrations of dissolved oxygen in Segment 15.

Dissolved oxygen in streams or rivers is suppressed by two kinds of biological processes: respiration (connected to organic matter) and nitrification (connected to ammonia). Both processes are affected by temperature. In addition, water holds less oxygen when it is warm. Thus, during warm months of the year, the rates of biological processes are highest and the oxygen-holding capacity of water is the lowest. Therefore, it is during warmer months when low concentrations of dissolved oxygen are most likely.

Oxygen concentrations vary hourly during the day as well as varying by seasons. The lowest concentrations of dissolved oxygen are most likely to occur at night, when there is no photosynthetic activity in the stream. Concentrations of dissolved oxygen in the stream during the day are significantly higher than at night due to the production of oxygen by aquatic photosynthesis.

The degree to which concentrations of dissolved oxygen are suppressed is also sensitive to the amount of flow in the river. When flow is low, the percentage of effluent in the river is high, and the concentration of ammonia is also higher. Significant compounding factors include reaeration and travel time, both of which may be most unfavorable during low flow. Spatial variation is important in this respect. Where reaeration in the stream is high because of turbulence, particularly below irrigation diversion dams, dissolved oxygen concentrations remain high even when flow is low and the water is warm.

V. WATER QUALITY GOALS

The goal of the TMDL process is to develop changes in Segment 15 that will allow Segment 15 to meet the dissolved oxygen standards at all locations, at all times of the year, and at all times of the day. The dissolved oxygen standard protects aquatic life from potentially harmful low concentrations of dissolved oxygen. Achievement of the water quality goal for dissolved oxygen will be assessed through monitoring of Segment 15 and water quality modeling.

Because the biological processes in the stream are complex and have changed over time, it will be necessary periodically to review monitoring data and modeling to assure that compliance is achieved and maintained. This is particularly true as additional urbanization occurs over the next 50 years. Compliance with dissolved oxygen standards should be monitored during critical periods of the year and the water quality model should be revised whenever there are major changes in the river. A reasonable schedule may be to update the model at intervals of five years, consistent with the discharge permit cycle.

VI. ANALYSIS OF SOURCES

Monitoring Related to Dissolved Oxygen: Over the past ten years, a large amount of water quality monitoring has documented sources of pollutants, concentrations of dissolved oxygen under varying conditions, and causes of dissolved oxygen depletion. Monitoring also has provided information for calibration of the Segment 15 Water

Quality Model for dissolved oxygen. Monitoring efforts have included:

1. Bi-weekly sampling at more than 5 locations along Segment 15 (by the Metro District and the South Platte Coalition for Urban River Evaluation [SP CURE);
2. Special 24-hour and 48-hour studies extending along the entire segment (Metro District, South Adams, and Brighton);
3. Special studies of travel time, biological processes, and reaeration (by the Metro District and EPA Region V); and
4. Special studies of ground water seepage, including rates and quality (by the United States Geological Survey [USGS])

The bi-weekly data are used in modeling. In addition, the special studies were designed and implemented specifically for the purpose of calibrating the water quality model. The cost of this monitoring has been well in excess of one-half million dollars and represents a very intensive approach to gathering the necessary water quality data for source assessment and for modeling.

Identification of Sources: The following is a brief assessment of the sources based on monitoring and modeling. The focus of this summary is ammonia, but organic matter (BOD_5 & $CBOD_5$) is also referenced.

Significant Point Source Dischargers to Segment 15 – Municipal wastewater treatment plants discharging to Segment 15 are the principal source of ammonia in the river. Because of the high volume of discharge from the Metro District (about 165 MGD annual average for future conditions), the ammonia from this source can influence essentially the entire segment during low flow periods. The added discharge from South Adams County Water and Sanitation District and the City of Brighton overlap the influence of the Metro District's discharge and could result in an increase in ammonia concentrations downstream of each of their discharges. All three dischargers also add organic matter (carbonaceous BOD expressed as $CBOD_5$) to the river. Table 2 below lists the effluent quantity and quality currently discharged by the major point source dischargers to Segment 15 (ammonia and BOD_5 or $CBOD_5$).

	Metro			South Adams			Brighton		
	Flow, mgd	NH4, mg/L	CBOD5, mg/L	Flow, mgd	NH4, mg/L	CBOD5, mg/L	Flow, mgd	NH4, mg/L	CBOD5, mg/L
Jan	**121.5**	**6.2**	**6.9**	**2.8**	**5.6**	**12.0**	**1.5**	**5.3**	**5.2**
Feb	116.6	5.8	6.3	2.7	5.7	11.0	1.5	3.9	5.0
Mar	**118.9**	**6.1**	**6.8**	**2.7**	**5.4**	**12.0**	**1.6**	**9.2**	**6.0**
Apr	135.4	5.8	6.3	2.7	4.4	12.1	1.6	11.8	5.0
May	**153.4**	**5.5**	**5.7**	**2.8**	**3.5**	**9.0**	**1.7**	**12.4**	**5.0**
Jun	153.8	4.9	6.3	2.9	4.4	12.0	1.8	7.1	4.0
Jul	**154.6**	**5.3**	**6.3**	**3.2**	**4.1**	**11.4**	**1.8**	**0.8**	**4.0**
Aug	156.7	5.4	5.1	3.3	2.9	10.0	1.9	2.0	4.0
Sep	**148.9**	**5.3**	**5.3**	**3.1**	**2.8**	**12.0**	**1.8**	**2.0**	**3.7**
Oct	143.3	5.9	5.3	3.0	3.0	12.0	1.7	3.0	4.0
Nov	**116.8**	**5.4**	**6.2**	**2.9**	**3.4**	**14.0**	**1.6**	**4.2**	**4.0**
Dec	114.9	5.9	6.8	2.8	3.9	15.0	1.5	5.6	4.0

Table 2. Summary of present characteristics for point source discharges to Segment 15.

Other Permitted Point Source Dischargers to Segment 15 – Currently there are a number of other permitted discharges to Segment 15; these discharges have low to very low concentrations of ammonia and organic matter or have very low volumes of discharge. Many of these sources are associated with ground water pumping for the purpose of dewatering excavation sites; in essence, they are discharging ground water that would normally reach the stream as seepage.

Contributions From Other Segments – Table 3 lists the normal monthly contributions of ammonia and organic matter into Segment 15 from Segment 14 (upstream), Sand Creek, and Clear Creek based on monitoring data. Contributions of ammonia and organic matter from these sources are negligible by comparison with the direct discharge to Segment 15 from municipal sources. For the purposes of this TMDL assessment, the upstream and tributary flows are as assumed in this table and are being considered as background. Should there be a proposal for a major plant expansion or a major increase in ammonia discharge to the tributaries or upstream flow, this assumption would need to be reconsidered, and potentially a revision of the TMDL assessment would be necessary.

Table 3. Source Water Conditions for Modeling

Chronic Conditions

	Upstream at 64th Ave			Sand Creek			Clear Creek		
	Flow, cfs	NH4, mg/L	CBOD5, mg/L	Flow, cfs	NH4, mg/L	CBOD5 mg/L	Flow, cfs	NH4, mg/L	CBOD5, mg/L
Jan	5.5	0.5	2.0	13.0	1.0	4.7	20.2	0.5	2.5
Feb	5.8	0.2	2.0	12.9	1.0	4.7	9.0	0.5	2.5
Mar	5.6	0.3	2.0	13.0	1.0	4.7	6.7	0.5	2.5
Apr	10.7	0.1	2.0	16.6	1.0	4.7	15.5	0.5	2.5
May	13.0	0.0	2.0	29.4	1.0	3.3	11.5	0.5	2.2
Jun	9.5	0.1	2.0	34.7	1.0	3.3	162.2	0.5	2.2
Jul	14.9	0.1	2.0	43.0	1.0	2.0	43.3	0.5	2.0
Aug	21.4	0.2	2.0	31.1	1.0	2.0	16.2	0.5	2.0
Sep	6.0	0.1	2.0	20.1	1.0	2.0	10.6	0.5	2.0
Oct	6.1	0.2	2.0	19.8	1.0	2.0	10.3	0.5	2.0
Nov	6.0	0.2	2.0	13.9	1.0	4.7	5.4	0.5	2.5
Dec	5.8	0.2	2.0	13.4	1.0	4.7	6.0	0.5	2.5

Flows at 64th are from DFLOW analyses
Flows in Sand and Clear Creeks differences of DFLOWS above and below confluences

Ammonia concentrations:
64th Ave set based on output from NO3 TMDL model
All others set to input values used in NO3 TMDL model

CBOD5 concentrations are from Segment 15 model

Table 3. Characteristics of upstream and tributary flows into Segment 15 at low flows.

Ground Water – Ground water seepage is a significant source of water in Segment 15. While the ground water contains nitrate at measurable levels, it contains ammonia and organic matter only at low concentrations. Special studies of gaged flows were used in developing the estimates of ground water seepage and ungaged flows shown in Table 4.

Seepage and Ungaged Flow
cfs/mi

	64th Ave. to Henderson	Henderson to Ft. Lupton
Jan	3.1	2.7
Feb	2.6	3.2
Mar	1.2	3.4
Apr	2.6	4.5
May	2.6	3.7
Jun	10.1	3.2
Jul	6.8	4.9
Aug	3.3	5.2
Sep	5.5	2.7
Oct	0.7	2.3
Nov	3.9	1.9
Dec	1.7	1.8

Includes seepage and a distributed component for small ungaged tributaries like Niver Creek

Chemistry for ungaged flows:
- Temp: set equal to that of stream
- pH: 7.2
- Dissolved Oxygen - DO: 4
- Carbonaceous Biochemical Oxygen Demand - CBOD5: 2
- Nitrate - NO3: 3 mg/L to 124th Ave;
  ramp linearly to 8.8 at RM 268.63 (St. Vrain confluence)
- Total Ammonia - NH4: set to 0.1 mg/L in all reaches

Table 4. Summary of characteristic seepage and ungaged flows contributions to Segment 15.

Storm Water – The lowest concentrations of dissolved oxygen in Segment 15 occur during low flows. Storm water from point and non-point sources can carry organic matter, some of which could be deposited in the stream channel. The importance of this source is minimal in comparison to the constant release of organic matter from the treatment facilities. Also, the large storm flows re-suspend settled materials and move them downstream. Overall, the amount of oxygen demand from storm flow is low in comparison to the demand caused by the municipal wastewater discharges. Furthermore, the feasibility of implementing a cost-effective and enforceable program to control storm water sources in the next 20 years is questionable.

Generation of Ammonia in Segment 15 – Decay of organic matter in the stream sediments and water column releases some ammonia into the stream. Modeling shows that the size of this source of ammonia is insignificant in comparison to the point sources.

Atmospheric Sources of Nutrients – Atmospheric sources of ammonia and organic matter are negligible in comparison to other sources for Segment 15.

Overview of Source Assessment - Conversion of total ammonia to nitrate in the stream by the naturally occurring biological process of nitrification is the primary cause of oxygen demand. Decomposition of organic matter is also an important cause of oxygen demand. Municipal wastewater effluent is the main source of both ammonia and organic matter. Therefore, the main control of oxygen demand must occur through regulation of point source discharges. However, optimization of oxygen supply (reaeration) is also very important and is achieved through changes in the river channel, as explained below.

Assessment of Factors Affecting Dissolved Oxygen in the Stream: Physical factors play a very significant role in controlling the concentrations of dissolved oxygen in Segment 15. The stream gains oxygen constantly through the natural process of reaeration. Where turbulence is high (over riffles or irrigation dams), the addition of dissolved oxygen by reaeration is the most efficient. In quiescent pools, the reaeration rate is lowest.

The concentration of dissolved oxygen in Segment 15 is affected by the combined influences of reaeration and the biological processes in the stream. During daylight hours, photosynthesis supplements reaeration as a source of dissolved oxygen in the water, while nitrification and decomposition simultaneously use oxygen. At night, reaeration continues, but without the assistance of photosynthesis, while nitrification and decomposition continue to demand oxygen. Thus the lowest concentrations of dissolved oxygen occur at night. These factors have been assessed through monitoring and have been incorporated into the Segment 15 Water Quality Model for dissolved oxygen.

VII. TECHNICAL ANALYSIS

Depression of dissolved oxygen in Segment 15 is largely driven by the amount of ammonia discharged to the stream by municipal dischargers. There are, however, a number of other factors that must be considered in the development of a plan to achieve dissolved oxygen standards. The concentration of dissolved oxygen in the stream is significantly influenced by photosynthesis and reaeration. Only a computerized water quality model can effectively account for these multiple influences on dissolved oxygen. The data gathered in the last ten years have allowed dissolved oxygen to be modeled with appropriate calibration based on the specific characteristics of Segment 15.

The Segment 15 Water Quality Model, which has been developed over the past ten years, considers all of the factors described above, plus many others that are necessary for accurate modeling. The model was originally based on EPA's STREAMDO model, but has been extensively tailored to Segment 15. The model is capable of predicting dissolved oxygen concentrations in the stream under low flow conditions. The model is calibrated to field measurements. Below is a brief summary of elements that are incorporated into the Segment 15 Water Quality Model:

Hydrology: Because the lowest concentrations of dissolved oxygen occur at low river flows, the model must be able to represent low flow conditions. Low flow projections by the model are based on extensive hydrologic data for the tributaries, irrigation diversions, effluent discharges (including projected increases in flow), and ungaged flows (mainly seepage). Fortunately, for Segment 15 there are a number of gage stations and good records of historical flows.

An internally consistent estimate of low flows on the South Platte main stem requires a special approach to the effect of tributaries and withdrawals on the flow of the main stem. A DFLOW analysis was conducted for both acute and chronic low flows above and below each tributary or water withdrawal (DFLOW is a Fortran program used to develop low flow values for permitting). The DFLOW analysis follows EPA methodology and is a means of estimating the biologically-based low flows. The analysis involves application of an algorithm that estimates, for acute (1-day) conditions, the annual low flow having a 3-year recurrence interval. This low flow applies to a particular month (the month in which it falls historically). Flows for other months are set either to their lowest observed value or to the annual DFLOW value, whichever is higher. For chronic low flows, the procedure is the same except the algorithm involves 30-day averaging by use of harmonic means, which are quite conservative in that they are disproportionately affected by the very lowest daily flows. The acute and chronic DFLOW calculations are used in routine permitting by the State. Table 5 contains an example of low flow for the river for the month of August. The model contains similar low flows for the other months.

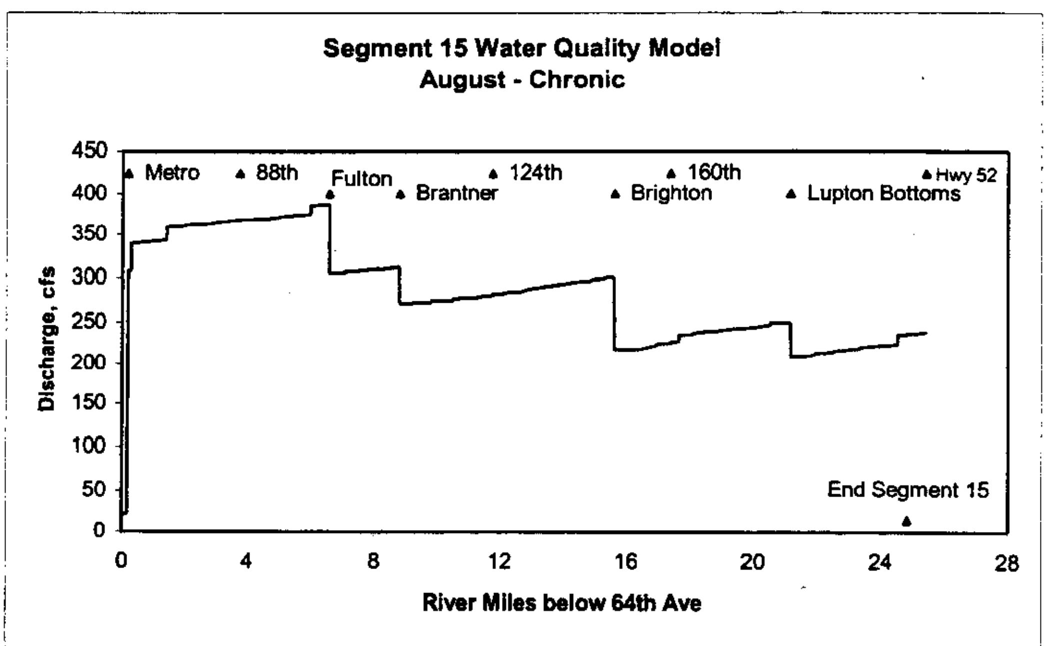


Table 5. Chronic modeling of low flows in the River for August.

Seasonal Considerations: There are three important seasonal changes to be considered in modeling. First, the dissolved oxygen standards are higher (more stringent) from April through July, when protection of early life stages of fish is most important. Second, the rates of nitrification change seasonally with temperature. Third, the flow regimes in the river differ significantly from season to season. Therefore, each month of the year needs to be evaluated separately. The model is set up so that each month can be run independently. For dissolved oxygen, the most critical months are July, August, September, and October. During the other months, there are not currently any known dissolved oxygen problems.

Source Assessment and Modeling Methodology: As described above in the section on analysis of sources, the river has been monitored intensively for about a decade. The accumulation of data has continuously improved the calibration of the model. The following list describes how various kinds of information are used in the model.

Point Source Discharges to Segment 15 – The major municipal discharges are treated as independent variables (See section below on Individual Source Contribution)

Other Permitted Point Source Discharges to Segment 15 – The other sources of direct discharge are low in volume or in ammonia and organic matter. These are not treated individually, but are given characteristic magnitudes for modeling. The TMDL needs to assure that future loadings from these sources do not become significant.

Contributions From Other Streams or Segments – These are incorporated into the model for Segment 14, Sand Creek, and Clear Creek based on historical water quality information and low flow analyses (e.g., dilution from these sources is set at regulatory low flow levels as explained above). The TMDL needs to assure that future loadings from these sources do not become significant. Minor tributaries (gulches, etc.) are incorporated as ungaged flows.

Ground Water – Ground water seepage is given characteristic magnitudes for quantity and quality for the upper and lower reaches of Segment 15.

Storm Water – The flow volumes from storm water events are not incorporated into the model, as the critical conditions occur at low flow.

Generation of Ammonia in Segment 15 – In-stream generation of ammonia is included in the model.

Atmospheric Sources - These sources are not significant in Segment 15 and are treated as background in the model.

Reaeration – The model incorporates different reaeration rates for different reaches of Segment 15 based on field measurements of reaeration.

Individual Source Contributions: Discharges from the Metro Wastewater Reclamation District, the South Adams Water and Sanitation District, and the City of Brighton are definable sources of ammonia. Because ammonia does not dissipate immediately in the stream, these sources overlap and therefore cannot be treated independently in modeling. These sources are expected to grow to serve the increasing population in the metropolitan Denver area. For these sources, the model incorporates projected future flows in the year 2010 as listed below:

Entity	Current Flow	2010 Modeled Flow
Metro Wastewater	155	165-175*
South Adams	2.9	7.0
Brighton	1.9	4.5

* Monthly at projected high monthly flows

Table 6. Current and future effluent flows.

Because of its large influence on Segment 15 , the Metro District's flow projections are included in the model separately for each month. As concentration of ammonia in the river is the most important consideration, relatively small changes in effluent flow from South Adams and Brighton affect the outcome of modeling very little. However, this northern service area is undergoing rapid urbanization and, as future combined flows from these sources reach 15 MGD, they will require more detailed modeling assessments and potentially a revision of this TMDL.

Biological Processes in Segment 15: Three major biological processes affect the concentrations of total ammonia and dissolved oxygen in Segment 15: respiration, photosynthesis, and nitrification. Each of these three processes varies seasonally and from one reach to another in Segment 15.

Respiration is characteristic of all forms of aquatic life, including microbes and algae. In the South Platte, as in most streams, the bulk of the total respiration is accounted for by microbes, which use oxygen in the process of converting organic matter (their energy source) to CO_2 and water. Respiration occurs in sediments, where it is classified for purposes of modeling as a component of SOD (sediment oxygen demand), and in the flowing water itself, where it is classified as carbonaceous BOD (CBOD). In general, respiration rates per unit area are higher in the sediments than in the water column because the supply of organic matter is greater in sediments, and because bacteria are very abundant in sediments as compared with the water column.

Respiration occurs continuously over the 24-hour cycle, but may vary considerably from one location to another or from one season to another. Respiration is highest where the supply of organic matter is richest. Although secondary treatment of municipal effluent results in removal of large amounts of organic matter, effluent typically contains more organic matter than stream water, and therefore tends to stimulate respiration below a wastewater outfall. For this reason, SOD and CBOD typically are higher in the upper end of Segment 15, where the influence of the Metro District outfall occurs, than in the lower end. Other outfalls show a similar effect, but on a smaller scale. Seasonally, respiration is stimulated by an increase in temperature. Greater flow also has effects, but these are more difficult to predict. Very high flows may remove organic matter that otherwise would be lodged in the sediment, whereas extended periods of low flow may allow accumulation of organic matter.

Most photosynthesis in the South Platte River is caused by attached algae. Attached algae sometimes are visible where the flow is very slow. Elsewhere, algae may be present but are virtually invisible because they do not grow to sufficient size to be seen. Although growth of algae on rocks and other stationary surfaces is natural for streams, algal growth in the South Platte River is probably stimulated by the large amounts of nutrients that are present in the segment. Algae are an important source of dissolved oxygen because they release oxygen as a byproduct of photosynthesis during the daylight hours. Algae also use oxygen during the daytime, but their release of oxygen typically outstrips their use of oxygen by a factor of 10:1 or more. At night, algae use oxygen for respiration, but their nocturnal rate of use in Segment 15 is far smaller than that of bacteria, and therefore is not an important consideration for the oxygen balance of the river.

Nitrification is the process by which ammonia (NH_3) is converted first to nitrite (NO_2) and then to nitrate (NO_3). This process is common both in water and soil wherever oxygen is present in combination with ammonia. The nitrification process is conducted by specialized types of bacteria that obtain energy from the conversion of ammonia to nitrate by use of oxygen. The process is beneficial for streams that receive ammonia from point source discharges or from non-point sources because it is a natural means by which ammonia is removed from the stream. On the other hand, rapid removal of ammonia by the process of nitrification constitutes a drain on the oxygen reservoir of the stream. As already explained, nitrification is an important contributor to the depression of oxygen concentrations in Segment 15.

For Segment 15, the concentration of ammonia in the stream is a major control on dissolved oxygen. Because the stream is predominately composed of effluent at critical low flows, it follows that the concentration of ammonia in the effluents is a critical variable. Setting poundage limitations in permits without regard to the flow volumes in the effluents and in the stream would be less secure than setting concentration limits.

Margin of Safety: For this TMDL assessment, a margin of safety is inherent within the assumptions incorporated into the water quality model. The modeling makes several worst case assumptions: (1) all dischargers are assumed to be discharging at design capacity; (2) all dischargers are assumed to be releasing the maximum allowable concentrations of regulated substances under their permits; (3) Segment 15 is assumed to be experiencing extreme low flows; and (4) in the case of the chronic dissolved oxygen standards, these same unfavorable combinations of conditions are assumed to be sustained for long intervals (2 - 4 weeks). It is unlikely that these model conditions will actually all occur at the same time.

A safety factor is also implicit within the normal operations of municipal wastewater treatment facilities. Municipal treatment plants are normally operated below permit limits because of the significant legal ramifications of permit violations. Table 2 shows the current performance of the three major municipal dischargers. While ammonia concentrations could increase some as flows increase, it is a reasonable presumption that municipal dischargers will operate at least 10-20% below their permit limitations. The combination of the conservative modeling assumptions and the municipal plant performance are reasonable and provide a significant margin of safety.

Assessments of Modeling Results and Development of Recommended Plan to Meet Dissolved Oxygen Standards: A plan for raising the concentrations of dissolved oxygen in Segment 15 has been under development since the early 1990s. The plan was established through a 1997 Memorandum of Understanding among the Metro Wastewater Reclamation District, the Colorado Water Quality Control Division, the U.S. Environmental Protection Agency, and the Colorado Division of Wildlife. Implementation of the plan is underway. The purpose of this section is to summarize the plan. More detailed information on the plan is contained in separate reports, which can be obtained from the agencies listed above.

Modeling shows that Segment 15 would not currently meet the dissolved oxygen standards at all locations on the river if point source dischargers all discharged at permit limits. This TMDL describes conditions under which the dissolved oxygen standards would be met throughout the segment at critical low flows and with discharges operating at permitted flow levels.

Figure 8. Reaeration at the Brantner Ditch diversion.

As indicated previously, dissolved oxygen can be depressed by biological activity in the stream. This biological activity can be controlled by limitations on ammonia and, to a lesser extent, by controls on organic matter discharged to the stream. Dissolved oxygen enters the stream through photosynthesis and reaeration. Reaeration has an effect on the river during both daylight and at night. In particular, irrigation diversion dams are known to play a very important role in adding oxygen to the river (Figure 8).

Figure 9 contains the model output (acute and chronic) for July period under current river conditions, but with 2010 effluent flows and current permit limits for ammonia. From this output, it can be seen that the river would not meet dissolved oxygen standards at all locations. A review of this output also shows that, below irrigation diversions, the river meets the dissolved oxygen standards because the dams produce efficient reaeration.

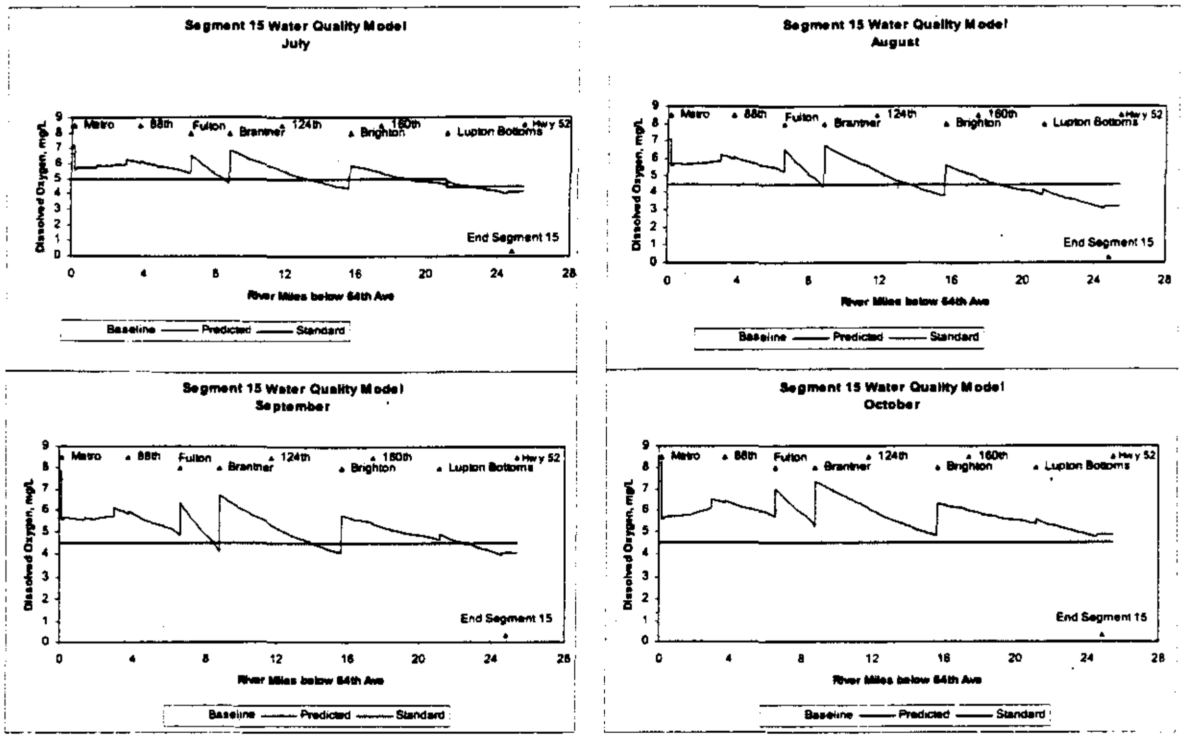


Figure 9. Graphs showing projected dissolved oxygen levels with no physical improvements and no new ammonia controls.

Low-head drop structures are a potentially valuable means for improving reaeration in the river. In 1995, as a test of this theory, the Metro District constructed a drop structure in the river about 4,000 feet upstream from 88th Avenue. This is a low head structure (2 foot drop) with a boat and fish passage chute in the center (Figure 10).

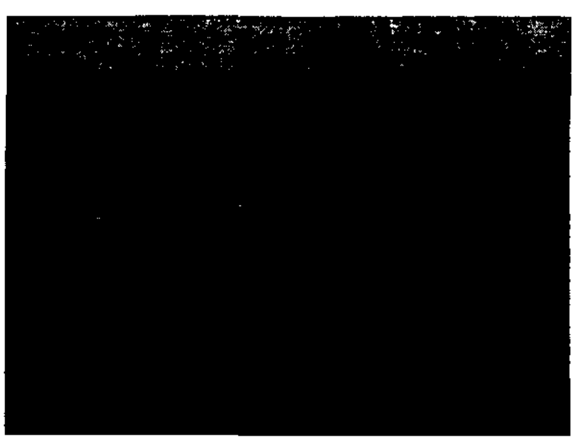


Figure 10. New reaeration structure upstream of 88th Avenue.

The structure adds reaeration due to the fall of water over the weir and the consequent entrainment of air into the water column. In addition, an erosion control dam at 88th Avenue was lowered to eliminate a flat section of river and create a more normal grade in the river bottom. Figure 11 shows that dissolved oxygen standards in this section of the river are now met under projected future conditions. Field monitoring verifies these improvements in dissolved oxygen and verifies that the dissolved oxygen standards are currently being met in this area.

As previously noted, oxygen depletion in the river is predominately driven by ammonia and to a lesser extent by organic matter. Modeling has shown that reductions in ammonia improve the concentration of dissolved oxygen, but that areas where standards are not achieved would continue to exist. From the modeling runs, it was determined that a set of stream improvements designed to increase reaeration would enable Segment 15 to meet the dissolved oxygen standards, provided that ammonia concentrations in the stream are also controlled.

Figure 11 shows graphs from the Segment 15 Water Quality Model for chronic conditions for each of the four critical months. For Segment 15, modeling has determined that meeting the chronic standards is expected to assure that the acute standards are also attained. The model runs show a set of reaeration structures that would increase reaeration in certain locations. These improvements are similar to the ones mentioned in the Memorandum of Understanding, but have been reconfigured based on the results of more recent modeling. Construction of these reaeration improvements, in combination with permit limits for ammonia, is expected to cause dissolved oxygen standards to be achieved throughout Segment 15 under future permitted flows. Implementation of this plan to meet the standards is addressed below.

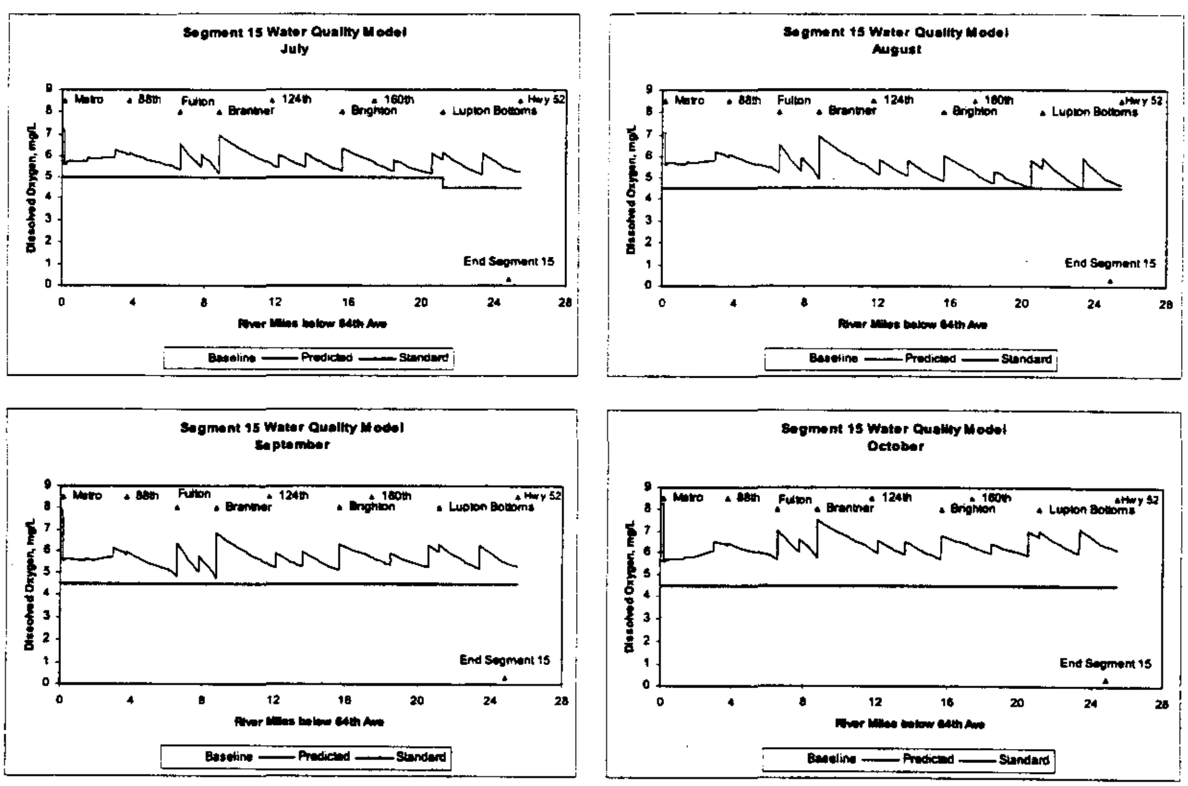


Figure 11. Model projections of dissolved oxygen with ammonia limits and physical improvements.

Table 7 shows the flows and ammonia loadings used in the model for the critical months of July, August, September, and October.

Location	Type	July			August			September			October		
		Flow	Ammonia		Flow	Ammonia		Flow	Ammonia		Flow	Ammonia	
		cfs	mg/L*	Lbs/day*	cfs	mg/L*	Lbs/day*	cfs	mg/L*	Lbs/day*	cfs	mg/L*	Lbs/day*
SP at 64th Ave	Tributary	15	0.1	4	21	0.2	11	6	0.1	2	6.1	0.2	3
Metro WWTP	**Discharge**	**285**	**10**	**6964**	**286**	**10**	**7003**	**277**	**10**	**6775**	**265**	**14**	**9061**
SP abv Sand Crk	In-stream	301	9.4	6932	309	9.3	7020	284	9.7	6750	271	13.7	9078
Sand Creek	Tributary	43	1	105	31	1	76	20	1	49	20	1	48
SP abv Clear Crk	In-stream	352	8.1	6978	343	8.3	6972	311	8.9	6766	291	12.7	9055
Clear Creek	Tributary	43	0.5	53	16	0.5	20	11	0.5	13	10	0.5	13
SP abv S Adams	In-stream	427	6.2	6476	375	7.1	6506	346	7.4	6270	305	11.7	8726
S Adams WWTP	**Discharge**	**11**	**10**	**264**	**11**	**10**	**264**	**11**	**10**	**264**	**11**	**14**	**370**
SP at Fulton	In-stream	442	6.2	6702	387	7.1	6728	361	7.3	6439	316	11.7	9049
SP abv Brighton	In-stream	361	3.4	3000	232	4.3	2443	257	5.9	3706	262	10.2	6532
Brighton WWTP	**Discharge**	**7**	**10**	**171**	**7**	**10**	**171**	**7**	**10**	**171**	**7**	**14**	**240**
SP abv Big Dry	In-stream	364	2.1	1871	231	2.4	1354	252	4.4	2713	258	8.8	5560

* 30 day average

Table 7. Ammonia load summary for Segment 15 (chronic standard, critical months only).

Control of the ammonia load is the most reasonable and implementable method of controlling oxygen demand in Segment 15. Adding reaeration is the most feasible method for increasing dissolved oxygen in quiescent areas of the stream where oxygen demand outstrips reaeration. While organic matter is not a major issue at this time, some control strategy for organic matter is also appropriate.

VIII. TMDL ALLOCATION

Allocation Methodology: Allocation of responsibilities for implementing the plan was developed primarily through discussion among the municipal dischargers that are affected by permit limits and other implementation requirements. The discussion among dischargers was facilitated through the South Platte Coalition for Urban River Evaluation (SP CURE), which is a cooperative of dischargers and water users in the Denver metropolitan area (Table 8). The main entities involved in these discussions on Segment 15 were the dischargers to Segment 15: Metro Wastewater Reclamation District, South Adams County Water and Sanitation District, and the City of Brighton.

1999 SP CURE Membership	
City of Aurora	City of Golden
City of Brighton	Littleton/Englewood Wastewater Treatment Facility
Centennial Water and Sanitation	Metro Wastewater Reclamation District
Conoco, Inc.	Public Service Company of Colorado
Coors Brewing Company	South Adams County Water and Sanitation District
City and County of Denver	City of Thornton
Denver Department of Environmental Health	
Farmers Reservoir and Irrigation Company	
City of Glendale	

Table 8. Members of South Platte Coalition for Cooperative River Evaluation (SP CURE).

The allocation discussions included responsibility for implementing stream improvements and allocation of ammonia loadings. As described previously, allocation of loadings is relevant only in context with the volume of flow. Therefore, concentration is being used for the allocation of ammonia and organic matter. Also, because significant future changes in flow could change the rate of biological processes and reaeration in Segment 15, it is recommended that the TMDL be reassessed when any of the wastewater treatment plants request expansion beyond the capacities cited above, or if the flow regime of the river is significantly altered for other reasons.

TMDL and Allocation Among Sources to be Controlled:

TMDL

1. The Metro Wastewater Reclamation District will be responsible for constructing all reaeration structures and other physical improvements in the channel that are necessary to meet the dissolved oxygen standards. This requirement will be included in the Metro District's discharge permit. The anticipated improvements are as follows: (a) One drop structure north of 104^{th} Avenue; (b) one or two drop structures between the Brantner Ditch diversion and the Brighton Ditch diversion; (c) construction of one drop structure north of the Brighton Ditch diversion and modification of the Fulton Ditch diversion dam; and (d) if necessary, one or more drop structures or other aeration improvements north of the Lupton Bottoms Ditch diversion.

   These structures will be constructed in an upstream to downstream progression that will facilitate monitoring of the performance achieved by each set of improvements. Where improvements do not achieve the dissolved oxygen standards, additional improvements must be installed or consideration given to more stringent ammonia standards for the dischargers. Also, based on the performance of improvements and updated modeling, adjustments to the projected number of structures, location, size, and reaeration techniques will be made as these improvements are implemented.

2. In order to meet dissolved oxygen stream standards in Segment 15, all dischargers to Segment 15 will have discharge permit limits for total ammonia. Based on the large volume of its discharge, the Metro District discharge has a greater effect on dissolved oxygen levels in Segment 15 than effluent from the smaller South Adams County Water and Sanitation District and City of Brighton wastewater treatment plants. Therefore, the total ammonia limits in Table 9 will be included in the discharge permit for the Metro District.

   Due to their smaller discharges, both the South Adams County Water and Sanitation District (4.4 MGD) and City of Brighton (2.65 MGD) wastewater treatment plants will initially have a monthly average total ammonia limit of 25 mg/L throughout the year. When either plant expands (South Adams County Water and Sanitation District above 4.4 MGD up to 7.0 MGD and Brighton above 2.65 MGD up to 4.5

MGD), then either the permit limits described in Table 9 will be used as permit limits or, at the option of the discharger seeking to expand capacity, additional modeling will be done as a basis for revising the TMDL. Updated modeling is expected to be carried out by the pertinent dischargers as South Adams and Brighton plan for expansions. Because the ammonia from all three discharges currently overlaps in Segment 15, it is feasible for an allocation strategy to be used whereby one facility removes more ammonia and another facility removes less.

Any other current discharges with significant amounts of total ammonia (concentrations greater than 2 mg/L) will have the permit limits listed in Table 9. Current dischargers with ammonia concentrations below 2 mg/L do not need ammonia permit limits unless the permit issuing authority determines they have a significant potential to exceed this criteria.

For any new discharger or expansion of an existing discharge, where that discharge would contain total ammonia concentrations greater than 2 mg/L and a volume of increased discharge greater than 0.2 MGD will require an amendment of the TMDL. South Adams County Water and Sanitation District expansion up to 7.0 MGD and City of Brighton expansion up to 4.5 MGD can occur without a mandatory revision of the TMDL.

Discharge Permit Limits (Table 9.)

Month	Maximum Monthly Average Total Ammonia Limits (mg/L)
January	15
February	15
March	14
April	14
May	13
June	13
July	10
August	10
September	10
October	14
November	14
December	15

Table 9. Discharge permit limits for total ammonia.

The total ammonia limits in Table 9 are specifically targeted to meet dissolved oxygen standards in Segment 15. Depending upon how the in-stream standard for un-ionized ammonia is regulated, future ammonia limits based on un-ionized ammonia may be more stringent than the limits cited above. Since it is impossible to predict the interrelated outcome of potential future regulatory changes, future total ammonia limits for any new discharge or expansion of an existing discharge will be determined on a case-by-case basis using water quality computer models for Segment 15. Additional modeling can be initiated at the option of the entity seeking a new or expanded discharge. If more stringent ammonia effluent limits are required to meet the un-ionized ammonia standards for protection of aquatic life, then these limits shall also be deemed as meeting the requirements of this TMDL. The Segment 15 Water Quality Model for dissolved oxygen or similar model will be revised, as necessary, for (1) expansions in treatment facilities; (2) the effects of the physical improvements made by the Metro District; and (3) changes in stream standards or the way in which compliance with the standards is determined by the permit issuing authority.

3. Dischargers with effluent concentrations less than 2 mg/L of total ammonia and an average discharge of less than 20 pounds per day of total ammonia are not considered significant from the viewpoint of dissolved oxygen, and will be exempt from the total ammonia permit requirements in Table 9, unless the permit issuing authority determines they have a significant potential to exceed this criteria.

4. Discharges into Segment 14, Clear Creek, and Sand Creek will be evaluated and permitted as follows. If the potential discharge of ammonia from a discharger, or set of dischargers, would cause the ammonia concentration in the tributary at the confluence with Segment 15 to exceed 2 mg/L total ammonia at the regulatory low flow used for the tributary in the model, then the same total ammonia permit limits cited above in Table 9 will be applied to those discharges (unless more stringent limits apply based on other water quality assessments).

5. For all permitted discharges to Segment 15, except storm water, BOD_5 and $CBOD_5$ will be limited to the secondary treatment maximum of 30 mg/L and 25 mg/L as a monthly average or the current permit limits where those are more stringent (the Metro District has more stringent $CBOD_5$ permit limits of 17 mg/L due to acceptance of a federal construction grant in the 1970s). Current dischargers with BOD_5 or $CBOD_5$ concentrations below 10 mg/L do not need BOD_5 or $CBOD_5$ permit limits unless the permit issuing authority determines they have a significant potential to exceed this criteria.

6. To prevent localized reductions in dissolved oxygen in the stream due to low dissolved oxygen in an effluent, the discharges from the Metro District will have dissolved oxygen permit limits of 5.0 mg/L as a 7-day average minimum and 3.0 mg/L as an instantaneous minimum. South Adams County Water and Sanitation District and the City of Brighton will have dissolved oxygen permit limits of 5.0 mg/L as a monthly average minimum and 3.0 mg/L as an instantaneous minimum. All other permitted discharges to Segment 15 will have a site-specific analysis to determine if dissolved oxygen effluent limits need to be incorporated into the permit

in order to assure that localized depression of the dissolved oxygen below standards does not occur due to discharge of low dissolved oxygen in the effluent. These dissolved oxygen limits will be addressed permit-by-permit based on an analysis suitable for each specific location. Where dissolved oxygen concentrations in the effluent is high enough that there is minimal probability of causing a localized oxygen depression, no permit limits will be necessary. Where possible, dischargers should use best management practices to increase the dissolved oxygen concentrations of their discharges.

Implementation: The TMDL requirements listed above, including the requirements for physical improvements, will be incorporated into discharge permits.

Monitoring: Monitoring for dissolved oxygen and ammonia in Segment 15 will be continued throughout the implementation phase and will continue after the completion of improvements for at least five locations in Segment 15. Specific locations for monitoring are not listed here as the locations will need to be adjusted as improvements are implemented. It is anticipated that the Segment 15 Water Quality Model will need to be re-calibrated with new data periodically. During the implementation phase, this model probably will be revised about every two years. After completion of the improvements, the model will be revised about every five years.

TMDL Revision: Because the biological and physical processes in Segment 15 are dynamic and because there is a significant probability of increased growth and urbanization along Segment 15, this TMDL assessment should be reviewed and revised at least every five years until it is clear that dissolved oxygen is no longer a problem in Segment 15. Specific proposals for increased or new discharges could trigger reviews and revisions at more frequent intervals. Because increased urbanization and increased wastewater flows are anticipated, dischargers should anticipate that ammonia limits could become more restrictive in the future. Designs of all new treatment plants and plant expansions should anticipate the need for the proposed facilities to meet potentially more stringent limits on ammonia in the future.

IX. PUBLIC INVOLVEMENT

The public involvement process for this TMDL has several components. The public has had the opportunity for involvement since the early 1990's when the site-specific dissolved oxygen standards were originally adopted, and the WQCC hearings held over the years regarding segment 15 have been conducted as a public process. In addition, the compilation of the 303(d) Lists has been a public process.

A public meeting was held in Denver on January 25th, 2000 to provide an update on the status of several TMDLs and to answer questions from the public. Approximately 50 people attended the meeting. The segment 15, D O TMDL was included in that meeting.

Finally, formal notice of the Division's intent to finalize this TMDL was published on March 3, 2000. Comments will be accepted through April 3, 2000.